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IAU/IUGG Joint Working Group on the Rotation of the Earth
Project MERIT

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OCTOBER 1983

INTERNATIONAL ASTRONOMICAL UNION
INTERNATIONAL UNION OF GEODESY AND GEOPHYSICS

Joint Working Group on the Rotation of the Earth

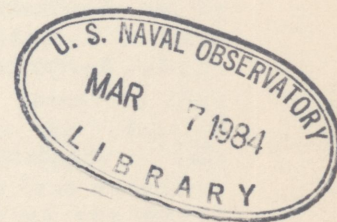
PROJECT MERIT STANDARDS

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Project MERIT

STANDARDS FOR THE MERIT CAMPAIGN

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MERIT STANDARDS

1. Introduction

1. Policy on Use of MERIT Standards

Introduction

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This document is intended to provide a common set of standards for the MERIT Campaign. It is intended to be used by all participants in the campaign, and to provide a common set of standards for the campaign. The objective of the campaign is to determine the Earth's Rotation Parameters (ERP), and it is essential that all techniques use compatible, if not identical, standards in the reduction of observations and in the subsequent comparison of results. In consequence with the IUGG 1983 Resolution on MERIT Standards (see footnote, pg 7 for text of resolution), and with the policy set by the MERIT Steering Committee, all participants in the MERIT campaign are required to comply with these standards.

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The main campaign of the MERIT Project is scheduled from September 1983, and will continue through October 1984. Therefore, it seems appropriate that the system of astronomical constants and reference systems scheduled to be introduced in the almanacs and ephemerides in 1984 should be used throughout the main MERIT Campaign in order to avoid the necessity of a change in systems during the Campaign. Use of this system in the MERIT Campaign may necessitate the duplication of reductions of observations by computing centers having the responsibility for determining and publishing Earth rotation parameters in the current system. However, it is felt that the early adoption of the new standards for the processing of data only for use in the MERIT Campaign will facilitate the subsequent intercomparison of observational methods. It must also be realized that the transformation between the pre- and post-1984 procedures is not trivial, and care must be exercised to avoid possible confusion.

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October 1983

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STANDARDS FOR THE MERIT CAMPAIGN

I. Introduction

a. Policy on Use of MERIT Standards

This document is intended to define the standard set of constants, models, and reference systems to be used by the observing stations and by the operational and analysis centers during the MERIT Campaign. To meet the objective of intercomparing current and new methods for the determination of the Earth Rotation Parameters (ERP), it is essential that all techniques use compatible, if not identical, standards in the reduction of observations and in the subsequent comparison of the results. In consonance with the IUGG 1983 Resolution on MERIT Standards (see footnote, pg 7 for text of resolution), and with the policy set by the MERIT Steering Committee, all participants in the MERIT campaign are urged to comply with the Standards in their entirety wherever practicable. If an individual operational or analysis center cannot fully comply with these guidelines, the center must carefully identify the exceptions. In these cases, the center is obliged to provide an assessment of the effects of the departures from the standards so that intercomparison of results by the MERIT Working Group will be possible. In the case of models, the use of models equivalent to those specified herein is acceptable, provided that the center establishes equivalency.

Different observing methods have varying sensitivity to the adopted standards and reference systems. No attempt has been made in this report to assess the sensitivity of each technique to the adopted reference systems and standards. Each technique should be aware of its own requirements and dependence on the adopted standards. The varying sensitivity of different techniques to the adopted constants and models may make comparison of techniques quite difficult, but these standards are intended to be a framework within which these comparisons can be made. For the purpose of achieving maximum accuracy in obtaining ERP results, the centers would be free to adjust those parameters and models that are appropriate for each technique in separate solutions from those designated for intercomparison.

The main campaign of the MERIT Project is scheduled from September 1983, and will continue through October 1984. Therefore, it seems appropriate that the system of astronomical constants and reference systems scheduled to be introduced in the almanacs and ephemerides in 1984 should be used throughout the main MERIT Campaign in order to avoid the necessity of a change in systems during the Campaign. Use of this system in the MERIT Campaign may necessitate the duplication of reductions of observations by computing centers having the responsibility for determining and publishing Earth rotation parameters in the current system. However, it is felt that the early adoption of the new standards for the processing of data only for use in the MERIT Campaign will facilitate the subsequent intercomparison of observational methods. It must also be realized that the transformation between the pre- and post-1984 procedures is not trivial, and care must be exercised to avoid possible confusion.

In practice, the constants and models are often used to produce observational ephemerides which are used in the actual reduction of observations. Investigators involved in the MERIT Campaign should be aware of the dependence of these generated ephemerides on the adopted standards in order to insure the consistency and compatibility of their results. It is suggested that all members of the MERIT Working Group be informed as quickly as possible of the availability of generated observational ephemerides which are consistent with the standards. Hopefully, this could minimize the duplication of efforts. The MERIT Subcommittee for standards will inform the Working Group members of ephemerides known to be compatible with these standards.

The standards of this report have been divided into Constants, Measurement Models, Dynamic Models, and Reference Systems. A few items remain where a consensus has not been obtained among the principal centers regarding the specific models or values to be recommended. These are indicated, and individual centers making use of models on which a consensus has not been reached must be careful to report the model which was actually used in the reduction of the observations.

b. Constants

The recommended system of astronomical constants correspond to those published with the lunar and planetary ephemerides contained in the 1984 Astronomical Almanac. This set is gravitationally consistent with these ephemerides. Otherwise, the constants specified are those adopted by the International Astronomical Union. These will be found in the Proceedings of the 16th General Assembly, Grenoble 1976, pp. 56-67, along with several recommendations and explanatory notes. They are also listed in the Connaissance des Temps 1980. The values of major interest to MERIT investigators are given below.

The units of length, mass, and time are in the International System of Units (SI) as expressed by the meter (m), kilogram (kg) and second (s). The astronomical unit of time is the day containing 86400 SI seconds. The Julian century contains 36525 days of atomic time. The Gaussian constant, $k = 0.01720209895$, is the defining constant relating the heliocentric gravitational constant (GS) to the astronomical unit of length (A) and to the unit of time through the relationship

$$GS = A^3 k^2$$

where GS is expressed in $m^3 s^{-2}$, A is the astronomical unit in meters and derived from the measured value of the astronomical unit in light-seconds and the defined value of the velocity of light in $m s^{-1}$, and k is $k/86400$.

c. Dynamical and Measurement Models

While a consensus has usually been attainable in standardizing the structural characteristics of a particular model, the adoption of specific values of the parameters within the model is more difficult to achieve in certain instances. If a technique is sensitive to a particular parameter in the sense that the determined ERP values are significantly impacted or

degraded by use of the Standard value, investigators at analysis centers should adjust it to obtain the best fit to the data and provide for intercomparison purposes the sensitivity of the ERP results to the departure of the parameter from the standard value. If the technique is not sensitive to a particular parameter, in the sense that minor or no degradation results, standardization, although less critical, should be maintained. The tables in Section II have noted the cases where adjustments and hence differences in values of parameters are likely to occur.

There remain a few instances where even the use of a common model has not been agreed to. For example, the choice of models and procedures for tropospheric and ionospheric corrections differs widely among the techniques and among the analysis centers. During the intercomparison phase, an assessment of the significant differences, if any, among these different approaches will have to be made.

d. Reference System

The treatment of reference frames will require special attention to avoid inconsistencies in intercomparing Earth rotation results from different techniques. In general, each technique uses different realizations of both the terrestrial and celestial frames. In addition, the techniques use different transformations between these frames. All centers for the different techniques are urged to use the IAU 1976 precession and IAU 1980 nutation models, (see Lieske et al, 1977, Lieske 1979, Appendix 3 of this report). The analysis centers use different transformations for relating the zero points of the longitudes of the terrestrial and celestial frames. In addition, the procedures for adopting terrestrial coordinates of observation sites differ among the techniques. Because of these differing conventions, the techniques will exhibit different absolute values and time histories for the ERP values.

It is noted that most centers have completed, or are in the process of, converting to a Julian epoch of J2000.0 (corresponding to Julian ephemeris date 2451545.0); this epoch is recommended for use in reference system algorithms. Further, the mean equator and equinox at J2000.0 is recommended as the space-fixed coordinate frame. The transformation from the 1950.0 frame to J2000.0 should use the IAU 1976 value of the precession constant. The definitive value of the correction to the FK4 equinox has been finalized (Fricke, 1981) to

$$E(T) = 0^s.035 + 0^s.085T$$

where T is measured in Julian centuries from 1950.0. This expression for E(T) is adopted and should be applied at the epoch J2000.0. A corresponding new relationship between Greenwich Mean Sidereal Time (GMST) and Universal Time must be used to avoid a discontinuity in UT1 results obtained by the stellar techniques. This expression is given by

$$\text{GMST at } 0^{\text{h}}\text{UT1} = 6^{\text{h}}41^{\text{m}}50^{\text{s}}.54841 + 8640184^{\text{s}}.812866T_u$$

$$+ 0^{\text{s}}.093104T_u^2 - 6^{\text{s}}.2 \times 10^{-6}T_u^3$$

where T_u is measured in Julian centuries from J2000.0. This expression

does lead, however, to a discontinuity and a change in rate of UT1 as measured by space techniques that are fixed to an inertial celestial frame. (See Williams and Melbourne, 1982; also Zhu & Mueller, 1983.) In Earth rotation studies, it is desirable to standardize on the celestial frames to be used. Different celestial or conventional quasi-inertial frames (CIS) will be used during the campaign: the stellar system, the radio source system, and dynamical systems defined by the lunar and planetary ephemerides or by artificial satellite ephemerides. These frames are rather loosely tied to each other but each forms a self-consistent frame that is needed by at least one of the techniques.

Adjustments to the existing FK4 positions and proper motions made necessary by the change in precession to the IAU 1976 value as well as by the equinox corrections and adjustment of star positions for the rigorous calculation of aberration "E terms" to be introduced on 1 January 1984, are outlined in Appendix 1. An outline of the general procedure for the calculation of the apparent places of stars and radio sources is given in Appendix 2. Although various computational techniques are available for this purpose, investigators should make sure that the procedures used in practice are compatible with the general outline.

Although the radio source CIS may be the best representation of an inertial frame that is available, accessibility of this system to techniques other than radio interferometry is difficult; the rotational uncertainty in right ascension between this frame and the FK5 catalog is about 0".2. A provisional list of radio source positions and a brief description of the origin in right ascension is provided in Appendix 12.

The dynamical CIS defined by the lunar and planetary ephemerides provides a more accessible reference frame. This system, defined by DE200/LE200, will be the basis for the ephemerides published in the Astronomical Almanac beginning in 1984. A further description of these ephemerides is found in Appendix 13. It should be noted that the mutual inclination and orientation of the ecliptic and equatorial planes in these new ephemerides are derived from meridian circle observations of the Sun and the planets and from LLR data taken from 1969 to 1982. The latter data set has become a strong and complementary information source along with planetary radar and spacecraft radio tracking data in the construction of the planetary ephemerides. This dynamical frame is relatively loosely tied in orientation to the FK5 frame. It is aligned in right ascension with the dynamical equinox at J2000.0 to an internal accuracy of 0".001. The realization of the dynamical equinox-of-date (circa MERIT campaign) using this system is probably accurate to about 0".01 in declination and 0".03 in right ascension. Although LLR analysis centers may adjust the lunar ephemeris to obtain the best fit for Earth rotation studies, it is recommended that the standard ephemeris system and associated constants be used to relate the LLR reference frame to those of other techniques.

The definition of the Terrestrial Reference Frame follows the recommendation of the Working Group formed as a result of the recommendation of IAU Colloquium No. 56: "As an interim reference system, the Working Group on Coordinate Reference Systems proposes that the system presently maintained

by the BIH should serve as reference for systems specific to various techniques. These should adjust their own system in such a way that it coincides with the BIH system as published in BIH Circulars D (Section 1). This adjustment should be made for a well-stated epoch and should use a sufficient interval of time to determine rotations. It is desirable that, as much as possible, the epoch of the short MERIT campaign be included in this time interval." For the MERIT Campaign, the axis of the geopotential model (GEM-L2) is offset from the direction of the CIO as realized by the BIH published values of polar motion (see Appendix 10). Similarly, the zero point in longitude is also defined by the BIH. It is important that the space techniques define clearly their adopted procedures for fixing their reference station positions and for alignment of the Earth rotation determinations with the BIH at one or more epochs. Attention is directed to the report by the MERIT Ad Hoc Working Group "Connection of Reference Frames" which addresses the procedures for determining the relationships between the terrestrial and space-fixed reference frames.

1983 IUGG Resolution on MERIT Standards

Noting that a goal of Project MERIT is to complete a comparative evaluation of the earth rotation results obtained by different techniques during a dedicated campaign, and

considering that detailed standards are being prepared to accomplish this goal,

recommends that all MERIT results be referred to these standards and

urges that all participants in the Project adhere to the constants, models and reference frames and to the protocols for their use as will be defined in the finally approved MERIT Standards Document.

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Lieske, J. H., Lederle, T., Fricke, W., and Morando, B., 1977, *Astron. Astrophys.*, 58, 1-16

Lieske, J. H., 1979, *Astron. Astrophys.*, 73, 282-284

Williams, J. G., and Melbourne, W. G., 1982, "Comments on the Effects of Adopting New Precession and Equinox Corrections," in *IAU Colloquium No. 63 Proceedings (High Precision Earth Rotation and Earth-Moon Dynamics: Lunar Distances and Related Observations)*, Ed., Odile Calame, Reidel, Dordrecht, 293-304

Zhu, S. Y. and Mueller, I. I., 1983, *Bull. Geod.* 57, 29-42

II. Standards

The tables herein, along with 15 appendices provide the MERIT Standards for constants, models, and reference frames. The format for the constants parallels closely that used by the IAU. The tables are organized into three columns: the item, the Standard value, and comments. The comments note departures from the IAU values and direct the reader to the appropriate appendix for an expanded discussion or listing of values. In some cases, the appendices contain tutorial material that might prove helpful.

References

Hopfield, H. S., 1973, J. Geophys. Res. 74 (18), pp 4487-4499

Jacchia, L. G., 1971, "Revised Static Models of the Thermosphere and Exosphere with Empirical Temperature Profiles," Smithson. Astrophys. Observ. Spec. Rep. 332, Cambridge, Mass.

Lieske, J. H., Lederle, T., Fricke, W., and Morando, B., 1977, Astron. Astrophys., 58, pp 1-16

Marini, J. W. and Murray, C. W., 1973, Correction of Laser Range Tracking Data for Atmospheric Refraction at Elevations Above 10 Degrees, NASA GSFC X-591-73-351

Yoder, C. F., Williams, J. G., Parke, M. E., 1981, J. Geophys. Res., 86, pp 881-891

ITEM

RECOMMENDED VALUE

COMMENTS

ASTRONOMICAL CONSTANTSDefining Constant

- Gaussian Gravitational Constant

$$k = 0.01720209895$$

- Velocity of Light

$$c = 2.99792458 \times 10^8 \text{ m s}^{-1}$$

Primary Constants

- Astronomical Unit in Light-Seconds

$$\tau_A = 499.00478370 \text{ s}$$

IAU (1976) Value = 499.004782 s

- Equatorial Radius of the Earth

$$a_e = 6378137 \text{ m}$$

IUGG Value; IAU Value = 6378140

- Dynamical Form Factor for Earth

$$J_2 = 0.00108263$$

Use Value in adopted gravity model adjusted to include zero frequency tide.

- Geocentric Constant of Gravitation

$$GE = 3.98600448 \times 10^{14} \text{ m}^3 \text{ s}^{-2}$$

IAU (1976) Value = $3.986005 \times 10^{14} \text{ m}^3 \text{ s}^{-2}$

- Constant of Gravitation

$$G = 6.672 \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}$$

- Earth-Moon Mass Ratio

$$\mu = 0.012300034$$

IAU (1976) Value = 0.0123002

- General Precession in Longitude Per Century for J2000.0

$$p = 5029''.0966$$

- Obliquity of the Ecliptic for J2000.0

$$s_o = \begin{cases} \text{Space Techniques: } 23^\circ 26' 21''.41190 \\ \text{Optical Techniques: IAU (1976)} \end{cases}$$

IAU (1976) Value = $23^\circ 26' 21''.448$.
Recommended values use rotating definition (see Appendix 13).Derived Constants

- Nutation Constant for J2000.0

This constant is superseded by the adoption of the IAU 1980 nutation based on the Wahr Nutation Model. See App. 3 for recommended Nutation Series in longitude and obliquity.

- Astronomical Unit

$$A = c\tau_A = 1.4959787066 \times 10^{11} \text{ m}$$

IAU (1976) value = $1.49597870 \times 10^{11} \text{ m}$

- Solar Parallax

$$\pi_o = \sin^{-1}(a_e/A) = 8''.794144$$

IAU (1976) Value = $8''.794148$

STANDARDS FOR MERIT CAMPAIGN

(continued)

ITEM	RECOMMENDED VALUE	COMMENTS
<u>Derive Constants</u> (continued)		
- Aberration Constant for J2000.0	In space techniques, the aberration corrections are calculated directly from ephemeris files.	IAU (1976) Value = 20".49552
- Earth Flattening	$f^{-1} = 298.257$	Uses the IAG (1975) value for ω of $\omega = 7.292115 \times 10^{-5} \text{ rad s}^{-1}$
- Heliocentric Constant for Gravitation	$GS = 1.32712440 \times 10^{20} \text{ m}^3 \text{ s}^{-2}$	IAU (1976) Value = $1.32712438 \times 10^{20} \text{ m}^3 \text{ s}^{-2}$
- Ratio of the Solar Mass to the Mass of the Earth	$GS/GE = 332,946.038$	IAU (1976) Value = 332,946.0
- Ratio of the Solar Mass to the Mass of the Earth-Moon System	$GS/GE(1+\mu) = 328,900.550$	IAU (1976) Value = 328,900.5
- Solar Mass	$S = 1.9891 \times 10^{30} \text{ kg}$	
<u>System of Masses</u> (Expressed in Reciprocal Solar Masses)		
- Mercury	6,023,600	
- Venus	408,523.5	
- Earth-Moon System	328,900.550	IAU (1976) Value = 328,900.5
- Mars	3,098,710	
- Jupiter	1,047.350	IAU (1976) Value = 1,047.355
- Saturn	3498.000	IAU (1976) Value = 3,498.5
- Uranus	22,960	IAU (1976) Value = 22,869
- Neptune	19,314	

STANDARDS FOR MERIT CAMPAIGN

(continued)

ITEM	RECOMMENDED VALUE	COMMENTS
<u>System Of Masses (continued)</u>		
- Pluto-Charon	130,000,000	IAU (1976) Value = 3,000,000
- Ceres	1.695×10^9	IAU (1976) Value = 1.7×10^9
- Pallas	9.247×10^9	IAU (1976) Value = 9.1×10^9
- Vesta	7.253×10^9	IAU (1976) Value = 8.3×10^9
<u>Lunar Gravitational Parameters for LLR</u>		
		The values of these parameters are consistent with the DE200/LE200 ephemerides but they are adjustable in LLR.
$\gamma = (B-A)/C$	2.280043×10^{-4}	IAU (1976) Value = 2.278×10^{-4}
$\beta = (C-A)/B$	6.316769×10^{-4}	IAU (1976) Value = 6.313×10^{-4}
C/MR^2	0.39053	IAU (1976) Value = 0.392
I^*	5553".5	IAU (1976) Value = $5552''.7 = 1^{\circ}32'32''.7$
GM^*	$4902.7993 \text{ Km}^3/\text{sec}^2$	
Love Number (k_2)	0.0222	
Rotational Dissipation (k_2^T)	$4.643 \times 10^{-3} \text{ days}$	
C_{20}	-2.02151×10^{-4}	IAU (1976) Value = -2.027×10^{-4}
C_{22}^*	2.2302×10^{-5}	IAU (1976) Value = $+2.23 \times 10^{-5}$
C_{30}	-8.626×10^{-6}	IAU (1976) Value = -6×10^{-6}
C_{31}	3.071×10^{-5}	IAU (1976) Value = $+2.9 \times 10^{-5}$
S_{31}	5.6107×10^{-6}	IAU (1976) Value = $+4 \times 10^{-6}$
C_{32}	4.8348×10^{-6}	IAU (1976) Value = $+4.8 \times 10^{-6}$

*Derived Constants

STANDARDS FOR MERIT CAMPAIGN

(continued)

ITEM	RECOMMENDED VALUE	COMMENTS
S ₃₂	1.684×10^{-6}	IAU (1976) Value = $+1.7 \times 10^{-6}$
C ₃₃	1.436×10^{-6}	IAU (1976) Value = $+1.8 \times 10^{-6}$
S ₃₃	-3.3435×10^{-7}	IAU (1976) Value = -1×10^{-6}
C ₄₀	1.5×10^{-7}	
C ₄₁	-7.18×10^{-6}	
S ₄₁	2.95×10^{-6}	
C ₄₂	-1.440×10^{-6}	
S ₄₂	-2.884×10^{-6}	
C ₄₃	-8.5×10^{-8}	
S ₄₃	-7.89×10^{-7}	
C ₄₄	-1.549×10^{-7}	
S ₄₄	5.64×10^{-8}	

DYNAMICAL MODELS**Geopotential****- Laser Satellites:**

GEM-L2 truncated to 20×20 for Lageos and the complete PGS-1331 for Starlette, C₂₁ and S₂₁ replaced by C₂₁(BIH) and S₂₁(BIH), and C₂₀ adjusted to include the zero frequency tide contribution.

The coefficients of GEM-L2 are given in Appendix 14. The PGS-1331 coefficients are in Appendix 15. The C₂₁(BIH) and S₂₁(BIH) are given in Appendix 10. The zero frequency correction is given in Appendix 5 (Eq. 5). Although GEM-L2 and PGS-1331 are based on values of GE different than the value given in Primary Constants of this Table, the recommended value for both fields is $GE = 3.98600448 \times 10^{14} \text{ m}^3 \text{ s}^{-2}$. It is recommended, however, that $a_0 = 6378144.11 \text{ m}$ be used with GEM-L2 and $a_0 = 6378137 \text{ m}$ be used with PGS-1331.

STANDARDS FOR MERIT CAMPAIGN

(continued)

RECOMMENDED VALUE

COMMENTS

ITEM

- LIR:

IAU (1976) zonals through degree 4

- Doppler Satellites:

GRIM 3B-M1

Drag

- Atmospheric Density Model

Jacchia, 1971

- Ballistic Coefficient $\Psi = C_D A / m$

C_D is an adjusted parameter

Starlette

GEOS-3

Lageos

Oscar

Nova

A	0.04524 m ²	1.437 m ²	0.283 m ²	1.3 m ²	2.2 m ²
m	47.295 kg	345.9 kg	407.0 kg	50 kg	126 kg

Radiation Pressure

- Reflectance Coefficient, C_R

The nominal value for Lageos is 1.14;
 C_R is an adjusted parameter

STANDARDS FOR MERIT CAMPAIGN

(continued)

ITEM	RECOMMENDED VALUE	COMMENTS
- Reflectance Model		See Appendix 4
- Earth Radiation Pressure	Ignored	
- Penumbra Model	6371000 m	Radius of earth for shadow model
<u>Solid Earth Tides</u>	Wahr Solid Tide Model for Earth Model 1066A. (Neglect third degree tides.)	See Appendix 5
<u>Ocean Tides</u>	Schwiderski Ocean Tide Model	See Appendix 6
<u>Relativistic Corrections</u>		
- Earth Satellites	Ignored: (SLR) Included: (Doppler)	See Appendix 8
- LLR	N-Body Formulation, $\gamma = \beta = 1$	Solar System Barycenter Integration
<u>Empirical Forces</u>		
- Lageos	$-C_T \times 10^{-12} \text{ m s}^{-2} \sqrt{V/V}$ per unit mass	C_T is an adjusted parameter that ranges from 0 to $^{-6}$ over time mean value over Lageos lifetime is around -3.1.
<u>Secular Acceleration of the Moon, $\dot{n}$</u>		$\dot{n}$ is an adjusted parameter in LLR. Value is near $-23 .8/\text{cy}^2$.
<u>MEASUREMENT MODEL</u>		
<u>Troposphere</u>		
- Dry Component, Doppler Only:	Surface meteorology measurement plus Hopfield model, (Hopfield, 1973).	
For SLR:	Surface meteorology measurement plus Marini and Murray Model (1973).	

STANDARDS FOR MERIT CAMPAIGN

(continued)

ITEM	RECOMMENDED VALUE	COMMENTS
<u>Net Component (microwave techniques)</u>		
- Doppler	Surface meteorology plus Hopfield model.	
- VLBI and CERI	Water vapor radiometry if available - otherwise, use model plus possible adjustment of vertical delay.	
<u>Satellite Center of Mass Correction</u>		
- Lageos	0.24 m	
- Starlette	0.075 m	
- GEOS-3	$(1.411 - 0.036 \frac{\phi}{\phi+3}) \cos(\phi - 22^{\circ}.473)$ m	ϕ = angle between line-of-sight and local vertical direction in degrees
- Oscar	1.0 m	Electrical center below center of mass.
- Nova	0.7 m	
<u>Solid Earth Tides, Displacements</u>		
	Wahr Solid Tide Model	See Appendix 5
<u>Ocean Loading Site Displacement</u>		
	Schwiderski tides	See Appendix 7
<u>Relativistic Corrections</u>		
- Propagation	Retardation and bending due to Sun ($\gamma = 1$).	See Appendix 9
- Time Epoch and Interval	Includes annual, diurnal, and other periodic terms.	See Appendix 9
- Doppler Shift	Due to Earth	See Appendix 9

STANDARDS FOR MERIT CAMPAIGN

(continued)

ITEM	RECOMMENDED VALUE	COMMENTS
<u>REFERENCE SYSTEMS</u>	1984 Conventions except as noted.	
<u>Space-Fixed Coordinate Frame</u>	Mean equinox and equator of J2000.0	Apply IAU 1976 Precession model (Lieske et al, 1977) and the equinox correction for the FK5 (see Introduction). Also see Appendix 1.
<u>Time Synchronization</u>	UTC as given by BIH	If using USNO UTC, then use USNO UTC-BIH UTC as published by BIH to correct to BIH UTC.
<u>Precession</u>	IAU 1976	See Lieske et al (1977) for application.
<u>Nutation</u>	IAU 1980	Based on Wahr Earth Model 1066A. Reference pole is the Celestial Ephemeris Pole (CEP). See Appendix 3.
<u>Terrestrial Coordinate Frame</u>	See report, "Connexion of Reference Frames," by MERIT Ad Hoc Working Group.	
<u>Tidal Variations in UT1</u>		See Appendix 11.
<u>VLBI Radio Source Positions and Designations</u>		See Appendix 12 for provisional source catalogs including right ascension zero points.
<u>Tectonic Motion</u>	0	
<u>Optical Positions</u>	FK5	See Appendices 1 and 2
<u>Ephemeris System</u>	Astronomical Almanac, 1984 (DE200/LE200).	Uses the Equinox and Equator of J2000.0. Origin in right ascension is set equal to the dynamical equinox of J2000.0. See Appendix 13.

STANDARDS FOR MERIT CAMPAIGN

(continued)

ITEM	RECOMMENDED VALUE			COMMENTS
<u>Lunar Reference Frame</u>				
- Retro-Reflector Coordinates (meters)				These coordinates are consistent with the DE200/LE200 ephemeris system but they are adjustable in LLR.
Apollo 11				
	X1	X2	X3	
PA	1592012.174	690605.998	21006.310	
ME	1591752.786	691221.955	20394.850	
	R	LONG	LAT	
PA	1735477.073	23.45093088	.69352820	
ME	1735477.073	23.47299617	.67333975	
Apollo 14				
	X1	X2	X3	
PA	1652662.237	-521095.647	-109727.640	
ME	1652821.419	-520455.963	-110364.156	
	R	LONG	LAT	
PA	1736339.050	-17.50041767	-3.62321101	
ME	1736339.050	-17.47866283	-3.64425710	
Apollo 15				
	X1	X2	X3	
PA	1554686.268	98004.046	765010.082	
ME	1554942.413	98604.650	764412.078	

STANDARDS FOR MERIT CAMPAIGN

(continued)

ITEM

RECOMMENDED VALUE

COMMENTS

Apollo 15 (continued)

	R	LONG	LAT
PA	1735481.089	3.60702873	26.15530389
ME	1735481.089	3.62847880	26.13331104

Lunakhod 2

	X1	X2	X3
PA	1339413.779	801793.356	756361.607
ME	1339394.295	802310.618	755847.426

	R	LONG	LAT
PA	1734642.539	30.90537743	25.85105146
ME	1734642.539	30.92203167	25.83218088

PA - Principal Axis Coordinates

ME - Mean Earth Coordinates

Rotation Angles between mean earth and principal axis coordinates
are $\tau = 79.815$ $P1 = -79.350$, $P2 = 0.295$ arcseconds.

Appendix 1: Adjustment of Celestial Reference System

This appendix describes the procedures for the conversion of several common types of existing astrometric reference data to the new standard epoch, J2000.0, so that the data may be used in accordance with the new IAU resolutions. It must be recognized that all such procedures are, to some extent, approximations. Rigorous conversion of reference data would require re-reduction of original observations. The former part of this appendix is based on the paper by Aoki et al. (1983) of the Tokyo Astronomical Observatory and the Japan Hydrographic Department. The latter part is largely excerpted from papers prepared at the U.S. Naval Observatory and edited by G.H. Kaplan dealing with changes made necessary by recent IAU recommendations.

Conversion of Epoch B1950.0 FK4-Based Positions and Proper Motions of Stars to Epoch J2000.0 Positions and Proper Motions in Accordance with the New IAU Resolutions and FK5 System

Note that:

- 1) The proper motion is corrected for the variations of the E-terms of aberration.
- 2) Transformation matrices of Step 3 in the following procedures are constructed so that the continuity of UT1 be guaranteed at 1984 Jan. 1.0, in accordance with the new relationship between the sidereal time and UT1 (Aoki et al., 1982).
- 3) The new precessional quantities are based on Lieske et al. (1977) (see Appendix 2) and the old values are based on Kinoshita (1975).
- 4) $0^s.035$ is adopted as the equinox correction at J1950.0 and $0^s.085$ as the equinox motion per Julian century (Fricke, 1982).

*** Step 1. Calculate the B1950.0 Position and Velocity Vectors.

$$\vec{r}_0 = (x_0, y_0, z_0) \text{ and } \dot{\vec{r}}_0 = (\dot{x}_0, \dot{y}_0, \dot{z}_0).$$

Here,

$$x_0 = \cos \delta_0 \cos \alpha_0, \quad y_0 = \cos \delta_0 \sin \alpha_0, \quad z_0 = \sin \delta_0,$$

$$\dot{x}_0 = -\mu_0 \sin \delta_0 \cos \alpha_0 - 15\mu_0 \cos \delta_0 \sin \alpha_0 + 21.094502 \pi_0 v_0 x_0,$$

$$\dot{y}_0 = -\mu_0 \sin \delta_0 \sin \alpha_0 + 15\mu_0 \cos \delta_0 \cos \alpha_0 + 21.094502 \pi_0 v_0 y_0,$$

$$\dot{z}_0 = \mu_0 \cos \delta_0 + 21.094502 \pi_0 v_0 z_0.$$

The proper motions μ_0 , μ_0' are in seconds of time per tropical century and arcseconds per tropical century at B1950.0, respectively. The stellar parallax π_0 is in arcseconds and the radial velocity v_0 in kilometers per second. Put $\pi_0 v_0 = 0$ if π_0 or v_0 is unknown. The factor 21.094502 is [km/au] · [tropical century/sec], where 1au = 1.49597870×10^8 km.

Note that $\dot{\vec{r}}_0$ is given in arcseconds per tropical century.

*** Step 2. Remove the Effects of the E-Terms of Aberration from B1950.0 Position and Velocity.

$$\vec{r}_1 = \vec{r}_0 - \vec{A} + (\vec{r}_0 \cdot \vec{A}) \vec{r}_0,$$

$$\dot{\vec{r}}_1 = \dot{\vec{r}}_0 - \dot{\vec{A}} + (\vec{r}_0 \cdot \dot{\vec{A}}) \vec{r}_0,$$

where $\vec{r}_1 = (x_1, y_1, z_1)$, $\dot{\vec{r}}_1 = (\dot{x}_1, \dot{y}_1, \dot{z}_1)$,

$$\vec{A} = 10^{-6}(-1.62557, -0.31919, -0.13843),$$

$$\dot{\vec{A}} = 10^{-3}(1.245, -1.580, -0.659).$$

$\vec{A}$ is the Earth's excess velocity beyond the mean velocity at perihelion in units of the light velocity.

Note that $\vec{r}_1$ and $\dot{\vec{r}}_1$ are given in arcseconds per tropical century.

$\vec{r}_1$ and $\dot{\vec{r}}_1$ are the position and velocity vectors of epoch B1950.0 without the effects of the E-terms of aberration.

*** Step 3. Convert the B1950.0 position and velocity x_1, y_1, z_1 and $\dot{x}_1, \dot{y}_1, \dot{z}_1$ to the J2000.0 position and velocity x, y, z and $\dot{x}, \dot{y}, \dot{z}$.

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} 0.9999256782 & -0.0111820610 & -0.0048579477 \\ 0.0111820609 & 0.9999374784 & -0.0000271765 \\ 0.0048579479 & -0.0000271474 & 0.9999881997 \end{pmatrix} \begin{pmatrix} x_1 \\ y_1 \\ z_1 \end{pmatrix} + \begin{pmatrix} 0.0000024239502 & -0.0000000271066 & -0.0000000117766 \\ 0.0000000271066 & 0.0000024239788 & -0.0000000000659 \\ 0.0000000117766 & -0.0000000000658 & 0.0000024241017 \end{pmatrix} \begin{pmatrix} \dot{x}_1 \\ \dot{y}_1 \\ \dot{z}_1 \end{pmatrix}$$

$$\begin{pmatrix} \dot{x} \\ \dot{y} \\ \dot{z} \end{pmatrix} = \begin{pmatrix} -0.00055 & -0.23854 & 0.43574 \\ 0.23849 & -0.00267 & -0.00854 \\ -0.43562 & 0.01225 & 0.00212 \end{pmatrix} \begin{pmatrix} x_1 \\ y_1 \\ z_1 \end{pmatrix} + \begin{pmatrix} 0.99994704 & -0.01118251 & -0.00485767 \\ 0.01118251 & 0.99995883 & -0.00002718 \\ 0.00485767 & -0.00002714 & 1.00000956 \end{pmatrix} \begin{pmatrix} \dot{x}_1 \\ \dot{y}_1 \\ \dot{z}_1 \end{pmatrix}$$

Note that $\dot{x}, \dot{y}, \dot{z}$ are given in arcseconds per Julian century.

When one calculates the apparent place at some required epoch using (x, y, z) and $(\dot{x}, \dot{y}, \dot{z})$ obtained here, go to Step 2, Case 1) in Appendix 2.

*** Step 4. Compute α , δ , μ , μ' , π , v of J2000.0 by the following formulas:

$$\cos \delta \cos \alpha = x/r ,$$

$$\cos \delta \sin \alpha = y/r ,$$

$$\sin \delta = z/r ,$$

$$\mu = (\dot{x}\dot{y} - \dot{y}\dot{x}) / (x^2 + y^2) / 15 ,$$

$$\mu' = [\dot{z}(x^2 + y^2) - z(\dot{x}\dot{x} + \dot{y}\dot{y})] / (r^2 \sqrt{x^2 + y^2}) ,$$

$$\pi = \pi_0 / r ,$$

$$v = 0.047404704 (\dot{x}\dot{x} + \dot{y}\dot{y} + \dot{z}\dot{z}) / (\pi_0 r) ,$$

where $r = \sqrt{x^2 + y^2 + z^2}$. Here, μ and μ' are in seconds of time per Julian century and in arcseconds per Julian century, respectively. The stellar parallax π is in arcseconds and the radial velocity v is in km/sec. The factor 0.047404704 is [au/km]·[sec/Julian century].

When one calculates the apparent place at some required epoch using (α , δ , μ , μ' , π , v) obtained in this step, go to Step 2, Case 2) in Appendix 2.

*** Step 5. Correct the position and proper motion of the epoch J2000.0 for distortions in the FK4 system (FK5-FK4 systematic differences), when known.

Conversion of Epoch B1950.0 Radio Source Position Catalogs

*** Step 1. Determine the (weighted) mean epoch of observations contributing to the catalog.

*** Step 2. Compute the mean place of each source at the mean epoch of observations, as determined in Step 1, using the B1950.0 mean places listed in the catalog, and the old (Newcomb) precession formulas (assuming the latter were used in the construction of the catalog).

*** Step 3. Add the following correction to the right ascensions of all the sources at the mean epoch of observations:

$$\Delta\alpha = 0^s.0775 + 0^s.0851 T + 0^s.0002 T^2$$

where T represents the mean epoch of observations, expressed in Julian centuries from JD 2451545.0 (1.5 Jan. 2000). Note that this is a correction for each catalog, and will generally be of order $0^s.060$ for most modern astrometric radio source catalogs. This adjustment corrects for the difference in sidereal time expressions in the old and new systems, and guarantees that a given source at the mean epoch of observations will have the same hour angle at a given UT1 time in the old and new systems (aside from the small periodic differences due to the use of different nutation theories). However, the corrections in precession and the catalog equinox drift term will produce a linear drift in the UT1 as measured by the space techniques. For further discussion, see the report prepared by an ad hoc MERIT Working Group on Reference Frame.

*** Step 4. Compute the mean place of each source at JD 2451545.0 (1.5 Jan. 2000) using the mean places at the mean epoch of observations (resulting from Steps 2 and 3) and the new precession formulas. I.e., use the new precession expressions to precess the source positions from the mean epoch of observations to epoch J2000.0.

*** Step 5. If necessary, subtract the E-terms of aberration from the J2000.0 mean places.

The mean places of the sources in the catalog have now been converted to equinox and equator J2000.0, in such a way that the catalog can now be used in accordance with the new IAU resolutions. For example, in the computation of observables, the new expressions for precession and sidereal time should be used.

N.B.

A preferred procedure for those with access to the original data from which the catalog was generated is as follows: Reduce the true of-date observations of the sources using the IAU 1980 Nutation, and IAU 1976 precession to mean positions at J2000.0. Align the origin of the right ascension of the catalog with the stellar frame in the same manner as followed for the epoch B1950.0 catalog with the stellar positions converted to J2000.0.

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Appendix 2: Procedure for Computing Apparent Places

The barycentric direction of a star at epoch TDB is calculated from its right ascension, declination and space motion for the standard equinox and equator of J2000.0 on the FK5 system.

Note that:

- 1) The distinction between TDB and TDT is not significant.
- 2) The space motion of the star is included but light time is ignored.
- 3) The relativity term for light deflection is modified to the asymptotic case where the star is assumed to be at infinity.

*** Step 1. Set TDB = TDT

*** Step 2. Obtain the Earth's barycentric position $\vec{E}_B$ in au and $\dot{\vec{E}}_B$ in au/day, at coordinate time $t = \text{TDB}$ referred to the equinox and equator of J2000.0. Then calculate the geocentric vector of the star at the required epoch on J2000.0 frame.

Case 1) When given the B1950.0 position and proper motion, calculate $\vec{P}$, the geocentric vector of the star at the required epoch t , using $x, y, z, \dot{x}, \dot{y}, \dot{z}$ obtained in Step 3 of 'Conversion' of Appendix 1 from :

$$\vec{P} = \vec{r} + T \vec{v} - \text{arc1}'' \pi_0 \vec{E}_B$$

where

$$\vec{r} = (x, y, z),$$

$$\vec{v} = \text{arc1}'' (\dot{x}, \dot{y}, \dot{z}),$$

and $T = (\text{JD} - 2451545.0)/36525$, which is the interval in Julian centuries from J2000.0, and JD is the Julian date at time t . π_0 is the stellar parallax at B1950.0 in arcseconds.

If $\vec{r}$ is given as the unit vector, π_0 should be replaced by π , the stellar parallax at J2000.0.

Case 2) When given the right ascension α , declination δ , proper motion in right ascension μ (in seconds of time per Julian century), proper motion in declination μ' (in arcseconds per Julian century), stellar parallax π (in arcseconds) and radial velocity v (in kilometers per second) at J2000.0, referred to the standard equinox and equator of J2000.0, calculate $\vec{P}$, the geocentric vector of the star at the required epoch t , from :

$$\vec{P} = \vec{r}' + T \vec{v}' - \text{arc1}'' \pi \vec{E}_B$$

where

$$\vec{r}' = (\cos \delta \cos \alpha, \cos \delta \sin \alpha, \sin \delta),$$

$$\vec{v}' = (v'_x, v'_y, v'_z),$$

$$v_x = \text{arc1}'' (-\mu' \sin \delta \cos \alpha - 15\mu \cos \delta \sin \alpha + 21.094953\pi v \cos \delta \cos \alpha),$$

$$v_y = \text{arc1}'' (-\mu' \sin \delta \sin \alpha + 15\mu \cos \delta \cos \alpha + 21.094953\pi v \cos \delta \sin \alpha),$$

$$v_z = \text{arc1}'' (\mu' \cos \delta + 21.094953\pi v \sin \delta),$$

$T = (JD - 2451545.0)/36525$, and JD is the Julian date at time t . The factor 21.094953 is [km/au]·[Julian century/sec].

*** Step 3. Form the heliocentric position of the Earth and calculate the geocentric direction of the star, corrected for light deflection.

Form the heliocentric position of the Earth ($\vec{E}$) from:

$$\vec{E} = \vec{E}_B - \vec{S},$$

where $\vec{S}$ is the barycentric position of the Sun at time t .

Form the geocentric direction ($\vec{p}$) of the star and the unit vector ($\vec{e}$) from $\vec{p} = \vec{P}/|\vec{P}|$ and $\vec{e} = \vec{E}/|\vec{E}|$.

Calculate the geocentric direction ($\vec{p}_1$) of the star, corrected for light deflection in the natural frame, from:

$$\vec{p}_1 = \vec{p} + (2\mu/c^2 E)[(\vec{e} - (\vec{p} \cdot \vec{e})\vec{p})/(1 + \vec{p} \cdot \vec{e})],$$

where the dot indicates a scalar product, $\mu/c^2 = 9.87 \times 10^{-9}$ au and $E = |\vec{E}|$.

The vector $\vec{p}_1$ is a unit vector to order μ/c^2 .

*** Step 4. Calculate the proper direction of the star ($\vec{p}_2$) in the geocentric inertial frame that is moving with the instantaneous velocity ($\vec{V}$) of the Earth relative to the natural frame, from:

$$\vec{p}_2 = (\beta^{-1} \vec{p}_1 + \vec{V} + (\vec{p}_1 \cdot \vec{V})\vec{V}/(1 + \beta^{-1}))/ (1 + \vec{p}_1 \cdot \vec{V}),$$

where $\vec{V} = \dot{\vec{E}}_B/c = 0.0057755 \dot{\vec{E}}_B$ and $\beta = (1 - V^2)^{-1/2}$; the velocity (V) is expressed in units of the velocity of light and is equal to the Earth's velocity in the barycentric frame to order V^2 .

*** Step 5. Apply precession and nutation to the proper direction ($\vec{p}_2$) by multiplying by the rotation matrices due to the precession [P] and the nutation [N] (Mueller, 1969), to obtain the apparent direction ($\vec{p}_3$), from:

$$\vec{p}_3 = [N][P]\vec{p}_2.$$

Here,

$$[P] = R_3(-Z_A) R_2(\theta_A) R_3(-\zeta_A),$$

$$[N] = R_1(-\epsilon_A - \Delta\epsilon) R_3(-\Delta\psi) R_1(\epsilon_A).$$

Rotation angles are defined by Lieske et al. (1977) as follows:

$$\begin{aligned}\zeta_A &= (2306''2181 + 1''39656 T - 0''000139 T^2) t \\ &\quad + (0''30188 - 0''000345 T) t^2 + 0''017998 t^3, \\ \theta_A &= (2004''3109 - 0''85330 T - 0''000217 T^2) t \\ &\quad + (-0''42665 - 0''000217 T) t^2 - 0''041833 t^3, \\ Z_A &= (2306''2181 + 1''39656 T - 0''000139 T^2) t \\ &\quad + (1''09468 + 0''000066 T) t^2 + 0''018203 t^3, \\ \epsilon_A &= (84381''448 - 46''8150 T - 0''00059 T^2 + 0''001813 T^3) \\ &\quad + (-46''8150 - 0''00117 T + 0''005439 T^2) t \\ &\quad + (-0''00059 + 0''005439 T) t^2 + 0''001813 t^3,\end{aligned}$$

where T represents Julian centuries from J2000.0 to an arbitrary epoch and t represents Julian centuries from the epoch to the date.

Note that the coefficient of Tt^2 in ζ_A has been changed to $-0''000344$ by Lieske (1979), but this change has no effect in our case because we need to calculate the precession from J2000.0 to the date and hence $T=0$.

$\Delta\psi$ and $\Delta\epsilon$ are the nutation in longitude and in obliquity, respectively (see Appendix 3 of Merit Standards).

*** Step 6. Convert to spherical coordinates (α_t, δ_t) using:

$$\xi/\rho = \cos\delta_t \cos\alpha_t,$$

$$\eta/\rho = \cos\delta_t \sin\alpha_t,$$

$$\zeta/\rho = \sin\delta_t,$$

where $\vec{p}_3 = (\xi, \eta, \zeta)$ and $\rho = \sqrt{\xi^2 + \eta^2 + \zeta^2}$.

REFERENCES

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Lieske, J.H., Lederle, T., Fricke, W., and Morando, B. : 1977, *Astron. Astrophys.* **58**, 1.
Mueller, I.I. : 1969, *Spherical and Practical Astronomy as Applied to Geodesy*, F. Ungar Publishing Co., Inc.

Appendix 3: Nutation Model (IAU 1980)

The recommended nutation series is given in Wahr (1981), Table 2 (included as Table 1 in this appendix) which has been adopted as the 1980 IAU nutation series. If calculations must be made to correct from the theory of E. W. Woolard as given in the Explanatory Supplement of the American Ephemeris to the Wahr theory, they should be made by Table 2 (here attached). A Fortran subroutine, giving the values of nutation in longitude and obliquity and their daily rates of change as a function of Julian date and decimal of date, is available from JPL or from USNO.

The Wahr model is based upon geophysical model 1066A of Gilbert and Dziewonski (1975), and therefore includes the effects of a solid inner core and a liquid outer core, and "a distribution of elastic parameters inferred from a large set of seismological data." The reasons for preferring the model of the Wahr-Smith proposal to other models, are summarized by Melchior (1980).

Two small terms of the 106 terms of John Wahr's theory have been revised from the tables given in his Thesis to those in Table 1. The Thesis includes a term $(-1, 0, 0, -2, 1)$ which does not appear in Table 1. The 7th term of Table 1 does not appear in the Thesis. Wahr points out (private communication) that the Thesis was based on a modification of a rigid Earth theory published by Kinoshita (1977), and Table 1 is based on a more recent manuscript of Kinoshita. The difference does not exceed ".0004. The values given here are presumably better, and are therefore recommended. It is noted that this nutation theory uses a new reference called the Celestial Ephemeris Pole (CEP), which has no diurnal motion.

Fundamental Arguments

The fundamental arguments of the nutation series, referenced to the epoch JD 2 451 545.0 = 2000 January 1.5 are given by the expressions:

$$l = 134^{\circ} 57' 46''.733 + (1325^r + 198^{\circ} 52' 02''.633) T + 31''.310 T^2 + 0''.064 T^3$$

$$l' = 357^{\circ} 31' 39''.804 + (99^r + 359^{\circ} 03' 01''.224) T - 0''.577 T^2 - 0''.012 T^3$$

$$F = 93^{\circ} 16' 18''.877 + (1342^r + 82^{\circ} 01' 03''.137) T - 13''.257 T^2 + 0''.011 T^3$$

$$D = 297^{\circ} 51' 01''.307 + (1236^r + 307^{\circ} 06' 41''.328) T - 6''.891 T^2 + 0''.019 T^3$$

$$\Omega = 125^{\circ} 02' 40''.280 - (5^r + 134^{\circ} 08' 10''.539) T + 7''.455 T^2 + 0''.008 T^3$$

where T is measured in Julian Centuries of 36525 days of 86400 seconds of Dynamical Time since J2000.0.

1980 IAU Theory of Nutation

Appendix 3; Table 1

Series for nutation in longitude $\Delta\Psi$ and obliquity $\Delta\epsilon$, referred to the mean equator and equinox of date, with T measured in Julian centuries from epoch J2000.0.

	ARGUMENT					PERIOD (DAYS)	LONGITUDE (.0001")		OBLIQUITY (.0001")	
	I	I'	F	D	Ω					
1	0	0	0	0	1	6798.4	-171996	-174.2T	92025	8.9T
2	0	0	0	0	2	3399.2	2062	.2T	-895	.5T
3	-2	0	2	0	1	1305.5	46	0.0T	-24	0.0T
4	2	0	-2	0	0	1095.2	11	0.0T	0	0.0T
5	-2	0	2	0	2	1615.7	-3	0.0T	1	0.0T
6	1	-1	0	-1	0	3232.9	-3	0.0T	0	0.0T
7	0	-2	2	-2	1	6786.3	-2	0.0T	1	0.0T
8	2	0	-2	0	1	943.2	1	0.0T	0	0.0T
9	0	0	2	-2	2	182.6	-13187	-1.6T	5736	-3.1T
10	0	1	0	0	0	365.3	1426	-3.4T	54	-.1T
11	0	1	2	-2	2	121.7	-517	1.2T	224	-.6T
12	0	-1	2	-2	2	365.2	217	-.5T	-95	.3T
13	0	0	2	-2	1	177.8	129	.1T	-70	0.0T
14	2	0	0	-2	0	205.9	48	0.0T	1	0.0T
15	0	0	2	-2	0	173.3	-22	0.0T	0	0.0T
16	0	2	0	0	0	182.6	17	-.1T	0	0.0T
17	0	1	0	0	1	386.0	-15	0.0T	9	0.0T
18	0	2	2	-2	2	91.3	-16	0.1T	7	0.0T
19	0	-1	0	0	1	346.6	-12	0.0T	6	0.0T
20	-2	0	0	2	1	199.8	-6	0.0T	3	0.0T
21	0	-1	2	-2	1	346.6	-5	0.0T	3	0.0T
22	2	0	0	-2	1	212.3	4	0.0T	-2	0.0T
23	0	1	2	-2	1	119.6	4	0.0T	-2	0.0T
24	1	0	0	-1	0	411.8	-4	0.0T	0	0.0T
25	2	1	0	-2	0	131.7	1	0.0T	0	0.0T
26	0	0	-2	2	1	169.0	1	0.0T	0	0.0T
27	0	1	-2	2	0	329.8	-1	0.0T	0	0.0T
28	0	1	0	0	2	409.2	1	0.0T	0	0.0T
29	-1	0	0	1	1	388.3	1	0.0T	0	0.0T
30	0	1	2	-2	0	117.5	-1	0.0T	0	0.0T
31	0	0	2	0	2	13.7	-2274	-.2T	977	-.5T
32	1	0	0	0	0	27.6	712	.1T	-7	0.0T
33	0	0	2	0	1	13.6	-386	-.4T	200	0.0T
34	1	0	2	0	2	9.1	-301	0.0T	129	-.1T
35	1	0	0	-2	0	31.8	-158	0.0T	-1	0.0T
36	-1	0	2	0	2	27.1	123	0.0T	-53	0.0T
37	0	0	0	2	0	14.8	63	0.0T	-2	0.0T

(continued)

Appendix 3; Table 1 cont.

	ARGUMENT l l' F D Ω					PERIOD (DAYS)		LONGITUDE (.0001")		OBLIQUITY (.0001")	
38	1	0	0	0	1	27.7	63	.1T	-33	0.0T	
39	-1	0	0	0	1	27.4	-58	-.1T	32	0.0T	
40	-1	0	2	2	2	9.6	-59	0.0T	26	0.0T	
41	1	0	2	0	1	9.1	-51	0.0T	27	0.0T	
42	0	0	2	2	2	7.1	-38	0.0T	16	0.0T	
43	2	0	0	0	0	13.8	29	0.0T	-1	0.0T	
44	1	0	2	-2	2	23.9	29	0.0T	-12	0.0T	
45	2	0	2	0	2	6.9	-31	0.0T	13	0.0T	
46	0	0	2	0	0	13.6	26	0.0T	-1	0.0T	
47	-1	0	2	0	1	27.0	21	0.0T	-10	0.0T	
48	-1	0	0	2	1	32.0	16	0.0T	-8	0.0T	
49	1	0	0	-2	1	31.7	-13	0.0T	7	0.0T	
50	-1	0	2	2	1	9.5	-10	0.0T	5	0.0T	
51	1	1	0	-2	0	34.8	-7	0.0T	0	0.0T	
52	0	1	2	0	2	13.2	7	0.0T	-3	0.0T	
53	0	-1	2	0	2	14.2	-7	0.0T	3	0.0T	
54	1	0	2	2	2	5.6	-8	0.0T	3	0.0T	
55	1	0	0	2	0	9.6	6	0.0T	0	0.0T	
56	2	0	2	-2	2	12.8	.6	0.0T	-3	0.0T	
57	0	0	0	2	1	14.8	-6	0.0T	3	0.0T	
58	0	0	2	2	1	7.1	-7	0.0T	3	0.0T	
59	1	0	2	-2	1	23.9	6	0.0T	-3	0.0T	
60	0	0	0	-2	1	14.7	-5	0.0T	3	0.0T	
61	1	-1	0	0	0	29.8	5	0.0T	0	0.0T	
62	2	0	2	0	1	6.9	-5	0.0T	3	0.0T	
63	0	1	0	-2	0	15.4	-4	0.0T	0	0.0T	
64	1	0	-2	0	0	26.9	4	0.0T	0	0.0T	
65	0	0	0	1	0	29.5	-4	0.0T	0	0.0T	
66	1	1	0	0	0	25.6	-3	0.0T	0	0.0T	
67	1	0	2	0	0	9.1	3	0.0T	0	0.0T	
68	1	-1	2	0	2	9.4	-3	0.0T	1	0.0T	
69	-1	-1	2	2	2	9.8	-3	0.0T	1	0.0T	
70	-2	0	0	0	1	13.7	-2	0.0T	1	0.0T	
71	3	0	2	0	2	5.5	-3	0.0T	1	0.0T	
72	0	-1	2	2	2	7.2	-3	0.0T	1	0.0T	
73	1	1	2	0	2	8.9	2	0.0T	-1	0.0T	
74	-1	0	2	-2	1	32.6	-2	0.0T	1	0.0T	

(continued)

Appendix 3; Table 1 cont.

ARGUMENT <i>l l' F D Ω</i>					PERIOD (DAYS)	LONGITUDE (.0001")		OBLIQUITY (.0001")		
75	2	0	0	0	1	13.8	2	0.0T	-1	0.0T
76	1	0	0	0	2	27.8	-2	0.0T	1	0.0T
77	3	0	0	0	0	9.2	2	0.0T	0	0.0T
78	0	0	2	1	2	9.3	2	0.0T	-1	0.0T
79	-1	0	0	0	2	27.3	1	0.0T	-1	0.0T
80	1	0	0	-4	0	10.1	-1	0.0T	0	0.0T
81	-2	0	2	2	2	14.6	1	0.0T	-1	0.0T
82	-1	0	2	4	2	5.8	-2	0.0T	1	0.0T
83	2	0	0	-4	0	15.9	-1	0.0T	0	0.0T
84	1	1	2	-2	2	22.5	1	0.0T	-1	0.0T
85	1	0	2	2	1	5.6	-1	0.0T	1	0.0T
86	-2	0	2	4	2	7.3	-1	0.0T	1	0.0T
87	-1	0	4	0	2	9.1	1	0.0T	0	0.0T
88	1	-1	0	-2	0	29.3	1	0.0T	0	0.0T
89	2	0	2	-2	1	12.8	1	0.0T	-1	0.0T
90	2	0	2	2	2	4.7	-1	0.0T	0	0.0T
91	1	0	0	2	1	9.6	-1	0.0T	0	0.0T
92	0	0	4	-2	2	12.7	1	0.0T	0	0.0T
93	3	0	2	-2	2	8.7	1	0.0T	0	0.0T
94	1	0	2	-2	0	23.8	-1	0.0T	0	0.0T
95	0	1	2	0	1	13.1	1	0.0T	0	0.0T
96	-1	-1	0	2	1	35.0	1	0.0T	0	0.0T
97	0	0	-2	0	1	13.6	-1	0.0T	0	0.0T
98	0	0	2	-1	2	25.4	-1	0.0T	0	0.0T
99	0	1	0	2	0	14.2	-1	0.0T	0	0.0T
100	1	0	-2	-2	0	9.5	-1	0.0T	0	0.0T
101	0	-1	2	0	1	14.2	-1	0.0T	0	0.0T
102	1	1	0	-2	1	34.7	-1	0.0T	0	0.0T
103	1	0	-2	2	0	32.8	-1	0.0T	0	0.0T
104	2	0	0	2	0	7.1	1	0.0T	0	0.0T
105	0	0	2	4	2	4.8	-1	0.0T	0	0.0T
106	0	1	0	1	0	27.3	1	0.0T	0	0.0T

$$\epsilon_{J2000} = 23^{\circ}26'21''.448$$

$$\sin \epsilon_{J2000} = .39777716$$

Appendix 3; Table 2

Proposed Series Minus Woolard Series
(Woolard's Table 26 and Explanatory Supplement, pp. 44-45)

Epoch J2000.00 (JED 2451545.0)

T in Julian Centuries

	ARGUMENT 1 1' F D Q	PERIOD (DAYS)	LONGITUDE (.0001")	OBLIQUITY (.0001")
1	0 0 0 0 1	6798.4	504.7	-.50T
2	0 0 0 3 2	3399.2	-26.2	
3	-2 0 2 0 1	1305.5	1	
4	2 0 -2 0 0	1095.2	1	
5	-2 0 2 0 2	1615.7		-1
6	1 -1 0 -1 0	3232.9	-1	
7	0 -2 2 -2 1	6786.3	2	-1
8	2 0 -2 0 1	943.2	1	
9	0 0 2 -2 2	182.6	-456.7	-.30T
10	0 1 0 0 0	365.3	168.1	-.30T
11	0 1 2 -2 2	121.7	-21.2	
12	0 -1 2 -2 2	365.2	3.5	
13	0 0 2 -2 1	177.8	4.9	
14	2 0 0 -2 0	205.9	3	
15	0 0 2 -2 0	173.3	-1	
16	0 2 0 0 0	182.6	1.1	
17	0 1 0 0 1	386.0		1
18	0 2 2 -2 2	91.3	-1.1	
19	0 -1 0 0 1	346.6	-2	1
20	-2 0 0 2 1	199.8	-1	
21	0 -1 2 -2 1	346.6		
22	2 0 0 -2 1	212.3		
23	0 1 2 -2 1	119.6	1	
24	1 0 0 -1 0	411.8	-1	
25	2 1 0 -2 0	131.7	1	
26	0 0 -2 2 1	169.0	1	
27	0 1 -2 2 0	329.8	-1	
28	0 1 0 0 2	409.2	1	
29	-1 0 0 1 1	388.3	1	
30	0 1 2 -2 0	117.5	-1	
31	0 0 2 0 2	13.7	-236.8	93.5
32	1 0 0 0 0	27.6	36.9	-7
33	0 0 2 0 1	13.6	-43.6	1.7
34	1 0 2 0 2	9.1	-40	16.1
35	1 0 0 -2 0	31.8	-9	-1
36	-1 0 2 0 2	27.1	9	-3
37	0 0 0 2 0	14.8	3	-2

- Merit Standards -

Appendix 3; Table 2 (continued)

	ARGUMENT	PERIOD	LONGITUDE	OBliquITY
	1 1' F D 2	(DAYS)	(.0001")	(.0001")
-38	1 0 0 0 1	27.7	5	-2
39	-1 0 0 0 1	27.4	-1	2
40	-1 0 2 2 2	9.6	-7	4
41	1 0 2 0 1	9.1	-7	4
42	0 0 2 2 2	7.1	-6	2
43	2 0 0 0 0	13.8	1	-1
44	1 0 2 2 2	23.9	3	-1
45	2 0 2 0 2	6.9	-5	2
46	0 0 2 0 0	13.6	1	-1
47	-1 0 2 0 1	27.0	2	
48	-1 0 0 2 1	32.0	2	-1
49	1 0 0 2 1	31.7		
50	-1 0 2 2 1	9.5	-1	
51	1 1 0 2 0	34.8		
52	0 1 2 0 2	13.2		
53	0 -1 2 0 2	14.2	-1	
54	1 0 2 2 2	5.6	-2	
55	1 0 0 2 0	9.6		-1
56	2 0 2 2 2	12.8		
57	0 0 0 2 1	14.8		
58	0 0 2 2 1	7.1	-2	
59	1 0 2 2 1	23.9	1	
60	0 0 0 2 1	14.7		
61	1 -1 0 0 0	29.8	1	
62	2 0 2 0 1	6.9	-1	1
63	0 1 0 2 0	15.4		
64	1 0 2 0 0	26.9		
65	0 0 0 1 0	29.5		
66	1 1 0 0 0	25.6		
67	1 0 2 0 0	9.1		
68	1 -1 2 0 2	9.4		1
69	-1 -1 2 2 2	9.8	-1	1
70	-2 0 0 0 1	13.7		1
71	3 0 2 0 2	5.5	-1	1
72	0 -1 2 2 2	7.2	-1	1
73	1 1 2 0 2	8.9		-1
74	-1 0 2 2 1	32.6		1

- Merit Standards -

Appendix 3; Talbe 2 (continued)

	ARGUMENT 1 1' F D 2	PERIOD (DAYS)	LONGITUDE (.0001")	ELLIPTICITY (.0001")
75	2 0 0 0 1	13.8		-1
76	1 0 0 0 2	27.8		1
77	3 0 0 0 0	9.2	2	
78	3 0 2 1 2	9.3	2	-1
79	-1 0 0 0 2	27.3	1	-1
80	1 0 0 -4 0	10.1	-1	
81	-2 0 2 2 2	14.6	1	-1
82	-1 0 2 4 2	5.8	-2	1
83	2 0 0 -4 0	15.9	-1	
84	1 1 2 -2 2	22.5	1	-1
85	1 0 2 2 1	5.6	-1	1
86	-2 0 2 4 2	7.3	-1	1
87	-1 0 4 0 2	9.1	1	
88	1 -1 0 -2 0	29.3	1	
89	2 0 2 -2 1	12.8	1	-1
90	2 0 2 2 2	4.7	-1	
91	1 0 0 2 1	9.6	-1	
92	0 0 4 -2 2	12.7	1	
93	3 0 2 -2 2	8.7	1	
94	1 0 2 -2 0	23.8	-1	
95	0 1 2 0 1	13.1	1	
96	-1 -1 0 2 1	35.0	1	
97	0 0 -2 0 1	13.6	-1	
98	0 0 2 -1 2	25.4	-1	
99	0 1 0 2 0	14.2	-1	
100	1 0 -2 -2 0	9.5	-1	
101	0 -1 2 0 1	14.2	-1	
102	1 1 0 -2 1	34.7	-1	
103	1 0 -2 2 0	32.8	-1	
104	2 0 0 2 0	7.1	1	
105	0 0 2 4 2	4.8	-1	
106	0 1 0 1 0	27.3	1	

$$\sin \epsilon_{2000} = 0.39777716$$

Appendix 3: Nutation Model

References

Gilbert, F., and Dziewonski, A. M., 1975, Phil. Trans. R. Soc. Lond., Vol. A278, pp. 187-269

Kinoshita, H., 1977, Celestial Mechanics, Vol. 15, No. 3, pp. 277-326

Melchior, P., 1980, Astron. and Astrophys., Vol. 87, p.365

Wahr, J. M. 1981, Geophys. J. Roy. Astr. Soc., Vol. 64, pp. 705-727

Appendix 4: Radiation Pressure Model

For a near-earth satellite the solar radiation pressure acceleration, γ is given by:

$$\ddot{\gamma} = \kappa \left(\frac{A}{R} \right)^2 C_R \frac{A}{m} \frac{\vec{R}}{R}$$

where

$$\kappa = 4.5605 \times 10^{-6} \text{ newtons/m}^2$$

A = astronomical unit in meters

R = heliocentric radius vector to the satellite

A = cross-sectional area (m^2) of the satellite perpendicular to $\vec{R}$

m = satellite mass

C_R = reflectivity coefficient

The radiation pressure due to backscatter from the earth is ignored. The model for the Earth's shadow should include the umbra and the penumbra (Haley, 1973).

References

Haley, D., 1973, Solar Radiation Pressure Calculations in the Geodyn Program, EG&G Report 008-73, Prepared for NASA Goddard Space Flight Center.

where

k_2 = nominal second degree Love number

R_e = equatorial radius of the earth

μ_E = gravitational parameter for the earth

μ_j = gravitational parameter for the moon ($j=2$) and sun ($j=3$)

r_j = distance from geocenter to moon or sun

ϕ_j = body fixed geocentric latitude of moon or sun

λ_j = body fixed east longitude of moon or sun

Appendix 5: Solid Earth Tides

The solid earth tide model proposed for the MERIT campaign is based on an abbreviated form of the Wahr model (Wahr, 1980) using the earth model 1066A of Gilbert and Dziewonski (1975). (See Appendix 3.)

The Love numbers for the induced free space potential, k , and for the vertical and horizontal displacements, h and l , have been taken from Wahr's Thesis, Tables 13 and 16. The long period, diurnal, semi-diurnal terms are included. Third degree terms are neglected.

Calculations of the Potential Coefficients

The solid tide induced free space potential is most easily modelled as variations in the standard geopotential coefficients C_{nm} and S_{nm} (Eanes, et al, 1983, and Eanes, 1984). The Wahr model (or any other having frequency dependent Love numbers) is most efficiently computed in two steps. The first step uses a frequency independent Love number k_2 and an evaluation of the tidal potential in the time domain from a lunar and solar ephemeris. The second step corrects those arguments of a harmonic expansion of the tide generating potential for which the error from using the k_2 of Step 1 is above some cutoff.

The changes in normalized second degree geopotential coefficients for Step 1 are:

$$\Delta \bar{C}_{20} = \frac{1}{\sqrt{5}} k_2 \frac{R_e^3}{GE} \sum_{j=2}^3 \frac{GM_j}{r_j^3} P_{20} (\sin \phi_j) \quad (1a)$$

$$\Delta \bar{C}_{21} - i \Delta \bar{S}_{21} = \frac{1}{3} \sqrt{\frac{3}{5}} k_2 \frac{R_e^3}{GE} \sum_{j=2}^3 \frac{GM_j}{r_j^3} P_{21} (\sin \phi_j) e^{-i\lambda_j} \quad (1b)$$

$$\Delta \bar{C}_{22} - i \Delta \bar{S}_{22} = \frac{1}{12} \sqrt{\frac{12}{5}} k_2 \frac{R_e^3}{GE} \sum_{j=2}^3 \frac{GM_j}{r_j^3} P_{22} (\sin \phi_j) e^{-i2\lambda_j} \quad (1c)$$

where

k_2 = nominal second degree Love number

R_e = equatorial radius of the earth

GE = gravitational parameter for the earth

GM_j = gravitational parameter for the moon ($j=2$) and sun ($j=3$)

r_j = distance from geocenter to moon or sun

ϕ_j = body fixed geocentric latitude of moon or sun

λ_j = body fixed east longitude (from Greenwich) of sun or moon.

The changes in normalized coefficients from Step 2 are:

$$\Delta \bar{C}_{nm} - i \Delta \bar{S}_{nm} = A_M \sum_{s(n,m)} \delta k_s H_s \begin{pmatrix} 1 \\ -1 \end{pmatrix} e^{i\theta_s} \begin{matrix} n+m \text{ even} \\ n+m \text{ odd} \end{matrix} \quad (2)$$

where

$$A_m = \frac{(-1)^m}{R_e \sqrt{4\pi (2-\delta_{om})}}, \quad \delta_{om} = \begin{cases} 1 & m = 0 \\ 0 & m \neq 0 \end{cases}$$

δk_s = difference between Wahr model for k at frequency s and the nominal value k_2 in the sense $k_s - k_2$,

H_s = amplitude (m) of term at frequency s from the Cartwright and Tayler (GJRAS, 23, 45-74) and Cartwright and Edden (GJRAS, 33, 253-264) harmonic expansion of the tide generating potential,

$$\theta_s = \bar{n} \cdot \bar{\beta} = \sum_{i=1}^6 n_i \beta_i$$

where

$\bar{n}$ = six vector of multipliers of the Doodson variables

$\bar{\beta}$ = the Doodson variables, and

$$\delta S_{20} = 0.$$

The Doodson variables are related to the fundamental arguments of the nutation series (See Appendix 3) by:

$$\begin{aligned} s &= F + \Omega = \beta_2 \quad (\text{Moon's mean longitude}) \\ h &= s - D = \beta_3 \quad (\text{Sun's mean longitude}) \\ p &= s - \ell = \beta_4 \quad (\text{Longitude of Moon's mean perigee}) \\ N' &= -\Omega = \beta_5 \quad (\text{Negative longitude of Moon's mean node}) \\ p_1 &= s - D - \ell' = \beta_6 \quad (\text{Longitude of Sun's mean perigee}), \text{ and} \\ \tau &= \theta_g + \pi - s = \beta_1 \quad (\text{Time angle in lunar days reckoned from lower transit}) \end{aligned} \quad (3)$$

where

θ_g = mean sidereal time of the conventional zero meridian.

The normalized geopotential coefficients ($\bar{C}_{nm}$, $\bar{S}_{nm}$) are related to the un-normalized coefficients (C_{nm} , S_{nm}) by the following:

$$C_{nm} = N_{nm} \bar{C}_{nm}, \quad S_{nm} = N_{nm} \bar{S}_{nm}$$

$$N_{nm} = \sqrt{\frac{(n-m)!(2n+1)(2-\delta_{0m})}{(n+m)!}}$$

Using a nominal k_2 of 0.3 and an amplitude cutoff of 9×10^{-12} change in normalized geopotential coefficients, the summation $S(n,m)$ requires 6 terms for the diurnal species ($n=2, m=1$) modifying $\bar{C}_{21}$ and $\bar{S}_{21}$ and 2 semi-diurnal terms ($n=2, m=2$) modifying $\bar{C}_{22}$ and $\bar{S}_{22}$. With the exception of the zero frequency tide, no long period terms are necessary. Table 1 gives required quantities for correcting the (2,1) and (2,2) coefficients. The correction to $\bar{C}_{20}$ is discussed in more detail below.

TABLE 1

Step 2 Solid Tide Corrections When $k_2 = .3$ in Step 1

Using a Cutoff Amplitude of 9×10^{-12} for $A_m \delta k_s H_s$

Long Period Tides ($n=2, m=0$)

None except zero frequency tide.

Diurnal Tides ($n=2, m=1$)

Doodson Number	$\bar{n}$, argument multipliers							$A_m \delta k_s H_s \times 10^{12}$
	τ	s	h	p	N'	p_1		
145.555 (O_1)	1	-1	0	0	0	0	-16.4	
163.555 (P_1)	1	1	-2	0	0	0	-49.6	
165.545	1	1	0	0	-1	0	-9.4	
165.555 (K_1)	1	1	0	0	0	0	507.4	
165.565	1	1	0	0	1	0	73.5	
166.554 (ψ_1)	1	1	1	0	0	-1	-15.2	

TABLE I (continued)

Semi-Diurnal Tides (n=2, m=2)

Doodson Number	n, argument multipliers						
	τ	s	h	p	N'	p ₁	$A_m \delta k_s H_s \times 10^{12}$
255.555 (M2)	2	0	0	0	0	0	39.5
273.555 (S2)	2	2	-2	0	0	0	18.4

The Step 2 correction due to the K_1 constituent is given below as an example.

$$\begin{aligned}
 (\Delta \bar{C}_{21} \times 10^{12})_{K_1} &= 507.4 \sin (\tau+s) \\
 &= 507.4 \sin (\theta_g + \pi) \\
 &= -507.4 \sin (\theta_g)
 \end{aligned}$$

$$(\Delta \bar{S}_{21} \times 10^{12})_{K_1} = -507.4 \cos (\theta_g)$$

The total variation in geopotential coefficients due to the solid tide is obtained by adding the results of Step 2 (Eq. 2) to those of Step 1 (Eq. 1).

Treatment of the Permanent Tide

The mean value of $\Delta \bar{C}_{20}$ from Eq. 1a is not zero, and this permanent tide deserves special attention. Ideally, the mean value of the correction should be included in the adopted value of $\bar{C}_{20}$ and hence not included in the $\Delta \bar{C}_{20}$. The practical situation is not so clear because satellite derived values of $\bar{C}_{20}$ as in the GEM geopotentials have been obtained using a mixture of methods, some applying the corrections and others not applying it. There is no way to ensure consistency in this regard short of re-estimating $\bar{C}_{20}$ with a consistent technique. If this is done the inclusion of the zero frequency term in Eq. 1a should be avoided because k_2 is not the appropriate Love number to use for such a term.

The zero frequency change in $\bar{C}_{20}$ can be removed by computing $\Delta \bar{C}_{20}$ as

$$\Delta \bar{C}_{20}^* = \Delta \bar{C}_{20} \text{ (Eq. 1a)} - \langle \Delta \bar{C}_{20} \rangle \quad (4)$$

where

$$\begin{aligned}\langle \Delta \bar{C}_{20} \rangle &= A_0 H_0 k_2 \\ &= (4.4228 \times 10^{-8})(-0.31455)k_2 \\ &= -1.39119 \times 10^{-8}k_2.\end{aligned}$$

Using $k_2 = 0.3$ then

$$\langle \Delta \bar{C}_{20} \rangle = -4.1736 \times 10^{-9}$$

or

$$\langle \Delta J_2 \rangle = -\langle \Delta \bar{C}_{20} \rangle \sqrt{5} = 9.3324 \times 10^{-9}$$

The decision to remove or not to remove the mean from the corrections depends on whether the adopted $\bar{C}_{20}$ does or does not already contain it and on whether k_2 is a potential 'solve for' parameter. If k_2 is to be estimated then it must not multiply the zero frequency term in the correction. In the most recent data reductions leading to GEM-L2, the total tide correction was applied. If we assume the more recent data has most of the weight in the determination of $\bar{C}_{20}$ then we conclude that the permanent deformation is not included in the GEM-L2 value of $\bar{C}_{20}$. Hence, if k_2 is to be estimated, first $\langle \Delta \bar{C}_{20} \rangle$ must be added to $\bar{C}_{20}$ and then $\Delta \bar{C}_{20}^*$ should be used in place of $\Delta \bar{C}_{20}$ of Eq. 1a. The k_2 used for restoring the permanent tide should match what was used in deriving the adopted value of $\bar{C}_{20}$.

The GEM-L2 value of $\bar{C}_{20}$ is $-484.16499 \times 10^{-6}$ and does not include the permanent deformation. The tidal corrections employed in the computations leading to GEM-L2 were equivalent to Eq. 1a with $k_2 = 0.29$. Let $\bar{C}_{20}^*$ denote the coefficient which includes the zero frequency term; then the GEM-L2 and PGS-1331 values of $\bar{C}_{20}$ with the permanent tide restored are:

$$\bar{C}_{20}^*(\text{GEM-L2}) = -484.16499 \times 10^{-6} - 1.39119 \times 10^{-8} \times 0.29$$

$$\bar{C}_{20}^*(\text{GEM-L2}) = -484.169025$$

(5)

$$\bar{C}_{20}^*(\text{PGS-1331}) = -484.170054$$

These values for $\bar{C}_{20}^*$ are recommended for use with the respective gravity field during MERIT and should be added to the periodic tidal correction given as $\Delta \bar{C}_{20}^*$ in Eq. 4 to get the total time dependent value of $\bar{C}_{20}$. Note that this recommendation is not precisely equivalent to using the unmodified $\bar{C}_{20}$ value with the unmodified $\Delta \bar{C}_{20}$ from Eq. 1a because the MERIT recommendation for k_2 is 0.3 instead of 0.29 which was used in deriving GEM-L2 and PGS-1331.

Solid Tide Effect on Station Coordinates

The variations of station coordinates caused by solid earth tides predicted using Wahr's theory are also most efficiently implemented using a two-step procedure. Only the second degree tides are necessary to retain 0.01 m precision. Also terms proportional to y , $h+$, $h-$, z , $+$, $-$, $w-$ and $w+$ are ignored. The first step uses frequency independent Love and Shida numbers and a computation of the tidal potential in the time domain. A convenient formulation of the displacement is given in the documentation for the GEODYN program. The vector displacement of the station due to tidal deformation for Step 1 can be computed from

$$\Delta \hat{r} = \sum_{j=2}^3 \left(\frac{GM_j}{GE} \frac{r^4}{R_j^3} \right) \left\{ \left[3\ell_2 (\hat{R}_j \cdot \hat{r}) \right] \hat{R}_j + \left[3\left(\frac{h_2}{2} - \ell_2\right) (\hat{R}_j \cdot \hat{r})^2 - \frac{h_2}{2} \right] \hat{r} \right\} \quad (6)$$

GM_j = gravitational parameter for the moon ($j=2$) or the sun ($j=3$)

GE = gravitational parameter for the earth

$\hat{R}_j, R_j$ = unit vector from the geocenter to moon or sun and the magnitude of that vector

$\hat{r}, r$ = unit vector from the geocenter to the station and the magnitude of that vector

h_2 = nominal second degree Love number

ℓ_2 = nominal Shida number.

If nominal values for h_2 and ℓ_2 of 0.6090 and 0.0852 respectively are used with a cutoff of 0.005m of radial displacement only one term needs to be corrected in Step 2. This is the K_1 frequency where h from Wahr's theory is 0.5203. Only the radial displacement needs to be corrected and to sufficient accuracy this can be implemented as a periodic change in station height given by

$$\delta h_{STA} = \delta h_{K_1} H_{K_1} \left(-\sqrt{\frac{5}{24\pi}} \right) 3 \sin \phi \cos \phi \sin (\theta_{K_1} + \lambda)$$

where

$$\delta h_{K_1} = h_{K_1}(\text{Wahr}) - h_2(\text{Nominal}) = -0.0887$$

H_{K_1} = amplitude of K_1 term (165.555) in the harmonic expansion of the tide generating potential = 0.36878 m

ϕ = geocentric latitude of station

λ = east longitude of station

$$\Theta K_1 = K_1 \text{ tide argument} = \tau + s = \Theta_g + \pi$$

or simplifying

$$\delta h_{STA} = -0.0253 \sin \phi \cos \phi \sin (\Theta_g + \lambda)$$

The effect is maximum at $\phi = 45^\circ$ where the amplitude is 0.013 m.

There is also a zero frequency station displacement which may or may not be included in the nominal station coordinates. The mean correction could be removed analogously to the discussion above. When baselines of coordinates are compared at the few cm level, care must be taken that the correction was handled consistently. It is essential that published station coordinates identify how the zero frequency contribution was included.

If nominal Love and Shida numbers of 0.6090 and 0.0852 respectively are used with Eq. 6, the permanent deformation introduced is in the radial direction.

$$\begin{aligned} \Delta \hat{r} \cdot \hat{r} &= \sqrt{\frac{5}{4\pi}} (0.6090)(-0.31455) \left(\frac{3}{2} \sin^2 \phi - \frac{1}{2} \right) \\ &= -0.12083 \left(\frac{3}{2} \sin^2 \phi - \frac{1}{2} \right) \text{ meters} \end{aligned} \quad (7)$$

and in the north direction

$$\begin{aligned} \Delta \hat{r} \cdot \hat{e}_p &= \sqrt{\frac{5}{4\pi}} (0.0852)(-0.31455) 3 \cos \phi \sin \phi \\ &= -0.05071 \cos \phi \sin \phi \text{ meters} \end{aligned} \quad (8)$$

Solid Tide Effects on Deflection of the Vertical

TBD

References

Eanes, R. J., Schutz, B. and Tapley, B., Earth and Ocean Tide Effects on Lageos and Starlette, Proceedings of the Ninth International Symposium on Earth Tides, E. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, 1983.

Eanes, R. J., Ph.D. Dissertation, In Preparation, University of Texas at Austin, 1984.

APPENDIX 6: Ocean Tide Model

The dynamical effect of ocean tides is most easily implemented as periodic variations in the normalized geopotential coefficients. The variations can be written as (Eanes, et al, 1983, and Eanes, 1984):

$$\Delta \bar{C}_{nm} - i \Delta \bar{S}_{nm} = F_{nm} \sum_{s(n,m)} \sum_{+} \left(C_{snm}^{+} + i S_{snm}^{+} \right) e^{+i\theta_s} \quad (1)$$

where

$$F_{nm} = \frac{4\pi G \rho_w}{g} \left[\frac{(n+m)!}{(n-m)!(2n+1)(2-\delta_{om})} \right]^{1/2} \left(\frac{1+k'_n}{2n+1} \right)$$

$$g = GE/a_e^2 = 9.798261 \text{ ms}^{-2}$$

$$G = \text{The universal gravitational constant} = 6.672 \times 10^{-11} \text{ m}^3 \text{ kg}^{-1} \text{ s}^{-2}$$

$$\rho_w = \text{density of seawater} = 1025 \text{ kg m}^{-3}$$

$$k'_n = \text{load deformation coefficients } (k'_2 = -0.3075, k'_3 = -0.195, k'_4 = -0.132, k'_5 = -0.1032, k'_6 = -0.0892)$$

$$C_{snm}^{+}, S_{snm}^{+} = \text{ocean tide coefficients in m for the tide constituent } s \text{ (see Table 1)}$$

$$\theta_s = \text{argument of the tide constituent } s \text{ as defined in the solid tide model (Appendix 5).}$$

The summation, $\sum_{+}$, implies addition of the expression using the top signs (the prograde waves C_{snm}^{+} and S_{snm}^{+}) to that using the bottom signs (the retrograde waves C_{snm}^{-} and S_{snm}^{-}). The ocean tide coefficients C_{snm}^{+} and S_{snm}^{+} as used here are related to the Schwiderski (1983) ocean tide amplitude and phase by:

$$C_{snm}^{+} - i S_{snm}^{+} = -i \hat{C}_{snm}^{+} e^{i(\epsilon_{snm}^{+} + \chi_s)} \quad (2)$$

where

$\hat{C}_{snm}^+$ = ocean tide amplitude for constituent s using the Schwiderski notation

ϵ_{snm}^+ = ocean tide phase for constituent s

$$\chi_s = \begin{cases} 0 & \text{Semidiurnal, and long period} \\ \pi/2 & K_1; \text{ (or in general for constituents with } H_s < 0) \\ -\pi/2 & O_1, P_1, Q_1; \text{ (or in general for constituents with } H_s > 0) \end{cases}$$

For clarity, equation 1 is rewritten in two forms below:

$$\Delta \bar{C}_{nm} = F_{nm} \sum_{s(n,m)} \left[(C_{snm}^+ + C_{snm}^-) \cos \theta_s + (S_{snm}^+ + S_{snm}^-) \sin \theta_s \right] \quad (3a)$$

or

$$\Delta \bar{C}_{nm} = F_{nm} \sum_{s(n,m)} \left[\hat{C}_{snm}^+ \sin (\theta_s + \epsilon_{snm}^+ + \chi_s) + \hat{C}_{snm}^- \sin (\theta_s + \epsilon_{snm}^- + \chi_s) \right] \quad (3b)$$

$$\Delta \bar{S}_{nm} = F_{nm} \sum_{s(n,m)} \left[(S_{snm}^+ - S_{snm}^-) \cos \theta_s - (C_{snm}^+ - C_{snm}^-) \sin \theta_s \right] \quad (3c)$$

or

$$\Delta \bar{S}_{nm} = F_{nm} \sum_{s(n,m)} \left[\hat{C}_{snm}^+ \cos (\theta_s + \epsilon_{snm}^+ + \chi_s) - \hat{C}_{snm}^- \cos (\theta_s + \epsilon_{snm}^- + \chi_s) \right] \quad (3d)$$

The summation over $s(n,m)$ should include all constituents for which Schwiderski has computed a model. Except for cases of near resonance, the retrograde terms do not produce long period (> 1 day) orbit perturbations for the diurnal and semi-diurnal tides. The RMS of the along-track perturbations on Lageos due to the combination of all of the retrograde waves is less than 5 cm. Hence, although the impact of these perturbations should be investigated, they are ignored in the nominal model. For the long period tides, the retrograde terms can be ignored if the prograde terms are doubled.

For computing inclinations and node perturbations, only the even degree terms are required, but for the eccentricity and periape the odd degree terms are not negligible. Long period perturbations are only produced when the degree (n) is greater than 1 and the order (m) is 0 for long period tides, 1 for diurnal tides, and 2 for semi-diurnal tides. Finally, the ocean tide amplitudes and their effect on satellite orbits decrease with increasing degree, so truncation above degree 6 is justified for Lageos.

Thus, for the diurnal tides (K_1 , O_1 , P_1 , Q_1) only the $n=2,3,4,5,6$ and $m=1$ terms need be computed. For the semi-diurnal tides (M_2 , S_2 , N_2 , K_2) only $n=2,3,4,5,6$ and $m=2$ terms need be computed. For the long period tides (M_f , M_m , S_{sa}) only $n=2,3,4,5,6$ and $m=0$ terms need be computed. Table 1 gives the values required for each of the constituents for which Schwiderski has computed a model. Note that the units in Table 1 are cm and hence must be scaled to m for use with the constants given on A6-1.

The $n=2$, $m=2$ term for the S_2 argument can be modified to account for the atmospheric tide using the results of Chapman and Lindzen (1970). The modified values to be used instead of those in Table 1 are:

$$C_{22}^+ = 0.537 \text{ (cm)}, \quad S_{22}^+ = 0.321 \text{ (cm)}$$

For the most precise applications, more than the 11 terms listed in Table 1 need to be modelled. This can be accomplished by assuming that the ocean tide admittance varies smoothly with frequency and by using the Schwiderski values as a guide to the interpolation to other frequencies.

References

- Chapman, S. and Lindzen, R., Atmospheric Tides, D. Reidel, Dordrecht, 1970.
- Eanes, et al, 1983 and 1984 (See Appendix 5).
- Schwiderski, E., "Atlas of Ocean Tidal Charts and Maps, Part I: The Semidiurnal Principal Lunar Tide M_2 ," Maine Geodesy 6 (3-4), 1983 (See also Appendix 7).

APPENDIX 6, TABLE 1

OCEAN TIDE COEFFICIENTS FROM THE SCHWIDERSKI MODELS

ARGUMENT NUMBER	n	m	$\hat{C}_{snm}^+$ (CM)	ϵ_{snm}^+ (DEG)	C_{snm}^+ (CM)	S_{snm}^+ (CM)
057.555 SSA	2	0	.6215	221.672	-.8264	-.9284
057.555 SSA	3	0	.0311	1.735	.0019	.0621
057.555 SSA	4	0	.1624	92.674	.3244	-.0152
057.555 SSA	5	0	.2628	251.737	-.4991	-.1647
057.555 SSA	6	0	.4363	145.744	.4912	-.7213
065.455 MM	2	0	.5313	258.900	-1.0428	-.2046
065.455 MM	3	0	.0317	94.298	.0632	-.0047
065.455 MM	4	0	.0998	69.054	.1863	.0713
065.455 MM	5	0	.2279	292.291	-.4218	.1729
065.455 MM	6	0	.0660	39.882	.0847	.1014
075.555 MF	2	0	.8525	251.956	-1.6211	-.5281
075.555 MF	3	0	.0951	148.236	.1001	-.1617
075.555 MF	4	0	.2984	102.723	.5822	-.1315
075.555 MF	5	0	.2960	223.167	-.4050	-.4318
075.555 MF	6	0	.0880	107.916	.1675	-.0542
135.655 Q1	2	1	.5373	313.735	-.3715	-.3882
135.655 Q1	3	1	.3136	107.346	.0935	.2994
135.655 Q1	4	1	.2930	288.992	-.0953	-.2770
135.655 Q1	5	1	.2209	112.383	.0841	.2042
135.655 Q1	6	1	.0396	287.824	-.0121	-.0377
145.555 O1	2	1	2.4186	313.716	-1.6715	-1.7481
145.555 O1	3	1	1.3161	83.599	-.1467	1.3079
145.555 O1	4	1	1.4301	276.282	-.1565	-1.4215
145.555 O1	5	1	.9505	109.128	.3115	.8980
145.555 O1	6	1	.1870	282.623	-.0409	-.1825
163.555 P1	2	1	.9020	313.912	-.6256	-.6498
163.555 P1	3	1	.2976	39.958	-.2281	.1911
163.555 P1	4	1	.6346	258.311	.1286	-.6215
163.555 P1	5	1	.4130	104.438	.1030	.4000
163.555 P1	6	1	.0583	276.591	-.0067	-.0579
165.555 K1	2	1	2.8158	315.113	1.9950	1.9872
165.555 K1	3	1	.8925	33.752	.7421	-.4959
165.555 K1	4	1	1.9121	254.229	-.5197	1.8401
165.555 K1	5	1	1.2111	104.672	-.3068	-1.1716
165.555 K1	6	1	.1645	281.867	.0338	.1610

TABLE 1 (CONTINUED)

ARGUMENT NUMBER	n	m	$\hat{C}_{snm}^+$ (CM)	ϵ_{snm}^+ (DEG)	C_{snm}^+ (CM)	S_{snm}^+ (CM)
245.655 N2	2	2	.6516	321.788	-.4030	.5120
245.655 N2	3	2	.1084	171.923	.0152	-.1074
245.655 N2	4	2	.2137	141.779	.1322	-.1679
245.655 N2	5	2	.0836	5.034	.0073	.0832
245.655 N2	6	2	.0674	346.544	-.0157	.0656
255.555 M2	2	2	2.9551	310.553	-2.2453	1.9213
255.555 M2	3	2	.3610	168.623	.0712	-.3539
255.555 M2	4	2	1.0066	124.755	.8270	-.5738
255.555 M2	5	2	.2751	356.561	-.0165	.2746
255.555 M2	6	2	.4130	329.056	-.2124	.3542
273.555 S2	2	2	.9291	314.011	-.6682	.6456
273.555 S2	3	2	.2633	201.968	-.0985	-.2442
273.555 S2	4	2	.3716	103.027	.3621	-.0838
273.555 S2	5	2	.1365	3.772	.0090	.1362
273.555 S2	6	2	.1726	280.381	-.1698	.0311
275.555 K2	2	2	.2593	315.069	-.1832	.1836
275.555 K2	3	2	.0943	195.007	-.0244	-.0911
275.555 K2	4	2	.1059	103.521	.1029	-.0247
275.555 K2	5	2	.0382	.411	.0003	.0382
275.555 K2	6	2	.0467	281.357	-.0458	.0092

NOTES:

1. The Doodson variable multipliers ($\bar{n}$) are coded into the argument number (A) after Doodson (Proc. R. Soc. A, 100, 305-329, 1921) as:

$$A = n_1(n_2+5)(n_3+5) \cdot (n_4+5)(n_5+5)(n_6+5)$$

2. For the long period tides ($m = 0$), the value of $\hat{C}_{snm}^+$ used to compute C_{snm}^+ and S_{snm}^+ was twice that shown to account for the combined effect of the retrograde and prograde waves.
3. The spherical harmonic decomposition of Schwiderski's models was computed by C. Goad of the National Geodetic Survey.

Appendix 7-1: Ocean Loading Site Displacement

The site displacements resulting from the ocean tides have been compiled by Clyde Goad of NOAA/NGS, Rockville, Maryland. Tidal loading height displacement amplitude and phase values for 25 laser and VLBI station locations have been computed for the M2, S2, K2, N2, O1, K1, P1, Q1, and Mf ocean tides using models generated by Schwiderski (1978). The technique of Goad (1980) which uses integrated Green's functions was employed. The load deformation coefficients used in generating the Green's function integrals were taken from Farrell (1972). For the majority of stations, the displacement amplitudes are less than one centimeter. However, for the Natal, Bermuda, Samoa, and Kwajalein stations, the range of the tidal effect can reach 10 centimeters.

Tables 1 - 9 give the amplitude and phase values for the nine models. The phase convention of Schwiderski has been preserved. His phases for the diurnal tides are different by $+90$ degrees with the standard Doodson definition. The appendix contains a fortran program which will return the proper angular argument to be used with the Schwiderski phases. The height displacement can be found for a given constituent i as follows:

$$h(i) = \text{amp}(i) * \cos (\text{arg}(i, t) - \text{phase}(i))$$

where $\text{arg}(i,t)$ is generated by the subroutine in the Appendix. The total tidal displacement is found by summing over all 9 constituents. A negative $h(i)$ means that the surface at the predicted point has been lowered.

References

- Goad, C.C., Gravimetric Tidal Loading Computed from Integrated Green's Functions, J. Geophys. Res., 85, 2679-2683, May 10, 1980
- Farrell, W.E., Deformation of the Earth by Surface Loads, Rev. Geophys. Space Phys., 10, 761-797, 1972
- Schwiderski, E.W., Global Ocean Tides, Part 1, A Detailed Hydrodynamical Model, Rep TR-3866, U.S. Nav. Surface Weapons Center, Dahlgren, Va, 1978

TABLE 1

M2 HEIGHT DISPLACEMENT AMPLITUDES AND PHASES

STATION	LAT (DEG)	LOX (DEG)	HT (M)	AMP (CM)	PHASE (DEG)
ORRLAS	-35.625	148.955	929.000	0.926	126.041
NATLAS	-5.928	324.835	46.000	3.922	33.317
WETZEL	49.146	12.878	663.000	0.516	-64.131
ARELAS	-16.466	288.507	2452.000	0.515	159.314
HOPLAS	31.684	249.122	2383.000	0.185	-84.104
QUN076	39.973	239.060	1087.000	0.648	54.668
SAN076	32.601	243.159	1025.000	0.692	-44.883
STALAS	39.020	283.172	56.000	0.909	158.234
BDALAS	32.352	295.344	13.000	2.040	166.046
7082ML0104	41.934	248.579	1980.000	0.292	90.589
KOOTWK	52.178	5.810	85.000	0.643	-40.524
GOLDSTONE	35.424	243.114	1000.000	0.215	-8.281
OWENS VAL	37.232	241.705	1207.000	0.276	33.172
WESTFORD	42.622	288.512	124.000	0.979	-175.314
GRND TURK	21.460	0.868	28.000	0.514	-61.140
HALEAKELA	20.710	203.741	3048.000	1.188	-116.824
RAMLAS	28.227	279.394	10.000	1.195	171.822
SAMOA	-14.340	189.275	15.000	2.741	-6.705
MCDONALD	30.677	255.984	1983.000	0.082	-165.114
YARRAGADEE	-29.083	115.417	200.000	0.377	169.464
FINLAND	60.217	24.394	69.000	0.278	-60.665
KWAJALEIN	9.400	167.500	10.000	3.051	-46.713
GREECE	38.078	23.933	503.000	0.416	-65.716
GRASSE	43.755	6.921	1300.000	0.714	-71.235
TLRJPL	34.206	241.828	475.000	0.500	-27.919
SHOLAS	33.578	135.937	62.0	1.817	86.61

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TABLE 2

S2 HEIGHT DISPLACEMENT AMPLITUDES AND PHASES

STATION	LAT (DEG)	LON (DEG)	HT (M)	AMP (CM)	PHASE (DEG)
ORRLAS	-35.625	148.955	929.000	0.123	175.952
NATLAS	-5.928	324.835	46.000	1.319	49.320
WETZEL	49.146	12.878	663.000	0.142	-36.242
ARELAS	-16.466	288.507	2452.000	0.077	142.576
HOPLAS	31.684	249.122	2383.000	0.194	-107.053
QUN076	39.973	239.060	1087.000	0.126	147.050
SAN076	32.601	243.159	1025.000	0.335	-74.915
STALAS	39.020	283.172	56.000	0.245	-170.184
BDALAS	32.352	295.344	13.000	0.465	-162.218
7082ML0104	41.934	248.573	1980.000	0.134	178.623
KOOTWK	52.178	5.810	85.000	0.180	-20.113
GOLDSTONE	35.424	243.114	1000.000	0.139	-111.961
OWENS VAL	37.232	241.705	1207.000	0.102	-140.484
WESTFORD	42.622	288.512	124.000	0.268	-151.853
GRND TURK	21.460	0.868	28.000	0.150	-48.605
HALEAKELA	20.710	203.741	3048.000	0.461	-133.181
RAMLAS	28.227	279.394	10.000	0.297	-159.801
SAMOA	-14.340	189.275	15.000	0.586	-13.401
MCDONALD	30.677	255.984	1983.000	0.154	-126.645
YARRAGADEE	-29.083	115.417	200.000	0.136	-105.116
FINLAND	60.217	24.394	69.000	0.063	-24.467
KWAJALEIN	9.400	167.500	10.000	1.653	-28.208
GREECE	38.078	23.933	503.000	0.110	-44.718
GRASSE	43.755	6.921	1300.000	0.208	-44.668
TLRJPL	34.206	241.823	475.000	0.222	-82.017
SHOLAS				0.803	106.50

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TABLE 3

K2 HEIGHT DISPLACEMENT AMPLITUDES AND PHASES

STATION	LAT (DEG)	LON (DEG)	HT (M)	AMP (CM)	PHASE (DEG)
ORRLAS	-35.625	148.955	929.000	0.028	161.773
NATLAS	-5.928	324.835	46.000	0.366	48.944
WETZEL	49.146	12.878	663.000	0.034	-31.665
ARELAS	-16.466	288.507	2452.000	0.031	141.818
HOPLAS	31.684	249.122	2383.000	0.063	-91.364
QUNU76	39.973	239.063	1087.000	0.009	120.817
SANU76	32.601	243.159	1025.000	0.119	-68.931
STALAS	39.020	283.172	56.000	0.066	-174.460
BDALAS	32.352	295.344	13.000	0.139	-167.905
7082ML0104	41.934	248.579	1980.000	0.023	-164.286
KOOTWK	52.178	5.810	85.000	0.036	-14.067
GOLDSTONE	35.424	243.114	1000.000	0.050	-84.933
OWENS VAL	37.232	241.705	1207.000	0.031	-93.284
WESTFORD	42.622	288.512	124.000	0.073	-158.901
GRND TURK	21.460	0.868	28.000	0.041	-48.311
HALEAKELA	20.710	203.741	3048.000	0.145	-134.057
RAMLAS	28.227	279.394	10.000	0.072	-165.828
SAMOA	-14.340	189.275	15.000	0.155	-17.894
MCDONALD	30.677	255.984	1983.000	0.043	-108.068
YARRAGADEE	-29.083	115.417	200.000	0.020	-95.091
FINLAND	60.217	24.394	69.000	0.018	-1.211
KWAJALEIN	9.400	167.500	10.000	0.407	-30.360
GREECE	38.078	23.933	503.000	0.029	-40.111
GRASSE	43.755	6.921	1300.000	0.036	-77.950
TLRJPL	34.206	241.828	475.000	0.085	-69.971
SHOLAS				0.237	109.53

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TABLE 4

01 HEIGHT DISPLACEMENT AMPLITUDES AND PHASES

STATION	LAT (DEG)	LON (DEG)	HIT (M)	AMP (CM)	PHASE (DEG)
ORRLAS	-35.625	148.955	929.000	0.279	65.436
NATLAS	-5.928	324.835	46.000	0.240	14.270
WETZEL	49.146	12.878	663.000	0.081	-96.276
ARELAS	-16.466	288.507	2452.000	0.320	-165.262
HOPLAS	31.684	249.122	2383.000	0.463	22.291
QUN076	39.973	239.060	1087.000	0.703	37.224
SANC76	32.601	243.159	1025.000	0.795	23.220
STALAS	39.020	283.172	56.000	0.225	-1.811
BDALAS	32.352	295.344	13.000	0.353	5.935
7082ML0104	41.934	248.573	1980.000	0.391	32.772
KOOTWK	52.178	5.810	85.000	0.097	-76.559
GOLDSTONE	35.424	243.114	1000.000	0.611	29.043
OWENS VAL	37.232	241.705	1207.000	0.623	32.181
WESTFORD	42.622	288.512	124.000	0.263	-4.677
GRND TURK	21.460	0.868	28.000	0.040	15.378
HALEAKELA	20.710	203.741	3048.000	0.707	49.461
RAMLAS	28.227	279.394	10.000	0.208	11.248
SAMOA	-14.340	189.275	15.000	0.253	-136.697
MCDONALD	30.677	255.984	1983.000	0.318	17.142
YARRAGADEE	-29.083	115.417	200.000	0.653	6.393
FINLAND	60.217	24.394	69.000	0.111	-102.601
KWAJALFIN	9.400	167.500	10.000	0.669	-151.049
GREECE	38.078	23.933	503.000	0.051	-110.091
GRASSE	43.755	6.921	1300.000	0.058	-98.713
TLRJPL	34.206	241.828	475.000	0.772	26.675
SHOLAS				1.073	-146.40

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TABLE 5

K1 HEIGHT DISPLACEMENT AMPLITUDES AND PHASES

STATION	LAT (DEG)	LON (DEG)	HT (M)	AMP (CM)	PHASE (DEG)
ORRLAS	-35.625	148.955	929.000	0.277	115.698
NATLAS	-5.928	324.835	46.000	0.230	103.220
WETZEL	49.146	12.878	663.000	0.178	-57.532
ARELAS	-16.466	288.507	2452.000	0.647	-142.204
HOPLAS	31.684	249.122	2383.000	0.718	37.959
QUN076	39.973	239.060	1087.000	1.131	51.271
SAN076	32.601	243.159	1025.000	1.260	38.447
STALAS	39.020	283.172	56.000	0.334	-2.178
BDALAS	32.352	295.344	13.000	0.476	-2.393
7082ML0104	41.934	248.579	1980.000	0.618	47.202
KOOTWK	52.178	5.810	85.000	0.206	-60.269
GOLDSTONE	35.424	243.114	1000.000	0.973	44.004
OWENS VAL	37.232	241.705	1207.000	0.997	46.860
WESTFORD	42.622	288.512	124.000	0.393	-5.079
GRND TURK	21.460	0.868	28.000	0.050	-117.216
HALEAKELA	20.710	203.741	3048.000	1.245	58.024
RAMLAS	28.227	279.394	10.000	0.281	10.614
SAMOA	-14.340	189.275	15.000	0.364	-132.885
MCDONALD	30.677	255.984	1983.000	0.476	32.554
YARRAGADEE	-29.083	115.417	200.000	0.821	13.457
FINLAND	60.217	24.394	69.000	0.172	-52.072
KWAJALEIN	9.400	167.500	10.000	0.967	-125.660
GREECE	38.078	23.933	503.000	0.073	-87.143
GRASSE	43.755	6.921	1300.000	0.178	-62.104
TLRJPL	34.206	241.828	475.000	1.228	41.710
SHOLAS				1.388	-126.13

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TABLE 6

P1 HEIGHT DISPLACEMENT AMPLITUDES AND PHASES

STATION	LAT (DEG)	LON (DEG)	HT (M)	AMP (CM)	PHASE (DEG)
ORRLAS	-35.625	148.955	929.000	0.104	108.188
NATLAS	-5.928	324.835	46.000	0.084	102.333
WETZEL	49.146	12.878	663.000	0.054	-53.665
ARELAS	-16.466	288.507	2452.000	0.194	-144.099
HOPLAS	31.684	249.122	2383.000	0.226	36.437
QUN076	39.973	239.060	1087.000	0.347	50.818
SAN076	32.601	243.159	1025.000	0.395	37.196
STALAS	39.020	283.172	56.000	0.108	0.286
BDALAS	32.352	295.344	13.000	0.150	-1.153
7082ML0104	41.934	246.579	1980.000	0.197	46.362
KOOTWK	52.178	5.810	85.000	0.061	-59.003
GOLDSTONE	35.424	243.114	1000.000	0.303	43.234
OWENS VAL	37.232	241.705	1207.000	0.309	46.312
WESTFORD	42.622	288.512	124.000	0.125	-3.187
GRND TURK	21.460	0.868	28.000	0.012	-115.903
HALEAKELA	20.710	203.741	3048.000	0.363	57.854
RAMLAS	28.227	279.394	10.000	0.097	12.038
SAMOA	-14.340	189.275	15.000	0.125	-133.959
MCDONALD	30.677	255.984	1983.000	0.152	30.839
YARRAGADEE	-29.083	115.417	200.000	0.264	13.427
FINLAND	60.217	24.394	69.000	0.053	-48.234
KWAJALEIN	9.400	167.500	10.000	0.316	-126.892
GREECE	38.078	23.933	503.000	0.020	-78.506
GRASSE	43.755	6.921	1300.000	0.053	-58.412
TLRJPL	34.206	241.829	475.000	0.383	40.919
SHOLAS				0.445	-127.04

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TABLE 7

N2 HEIGHT DISPLACEMENT AMPLITUDES AND PHASES

STATION	LAT (DEG)	LON (DEG)	HT (M)	AMP (CM)	PHASE (DEG)
ORRLAS	-35.625	148.955	929.000	0.193	96.592
NATLAS	-5.928	324.835	46.000	0.894	20.898
WETZEL	49.146	12.878	663.000	0.110	-87.729
ARELAS	-16.466	288.507	2452.000	0.170	116.117
HOPLAS	31.684	249.122	2383.000	0.101	-76.422
QUN076	39.973	239.060	1087.000	0.132	-2.502
SAN076	32.601	243.159	1025.000	0.231	-65.109
STALAS	39.020	283.172	56.000	0.168	142.507
BDALAS	32.352	295.344	13.000	0.432	145.086
7082ML0104	41.934	248.579	1980.000	0.039	-1.678
KOOTWK	52.178	5.810	85.000	0.138	-67.641
GOLDSTONE	35.424	243.114	1000.000	0.114	-55.413
OWENS VAL	37.232	241.705	1207.000	0.100	-38.020
WESTFORD	42.622	288.512	124.000	0.210	168.265
GRND TURK	21.460	0.868	28.000	0.104	-74.962
HALEAKELA	20.710	203.741	3048.000	0.267	-137.596
RAMLAS	28.227	279.394	10.000	0.230	152.580
SAMOA	-14.340	189.275	15.000	0.717	-20.517
MCDONALD	30.677	255.984	1983.000	0.054	-69.972
YARRAGADEE	-29.083	115.417	200.000	0.067	96.064
FINLAND	60.217	24.394	69.000	0.059	-89.816
KWAJALEIN	9.400	167.500	10.000	0.498	-45.399
GREECE	38.078	23.933	503.000	0.092	-91.490
GRASSE	43.755	6.921	1300.000	0.150	-92.222
TLRJPL	34.206	241.828	475.000	0.188	-57.903
SHOLAS				0.360	91.55

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TABLE 8

Q1 HEIGHT DISPLACEMENT AMPLITUDES AND PHASES

STATION	LAT (DEG)	LON (DEG)	HT (M)	AMP (CM)	PHASE (DEG)
ORRLAS	-35.625	148.955	929.000	0.083	51.114
NATLAS	-5.928	324.835	46.000	0.066	-14.713
WFTZEL	49.146	12.873	663.000	0.006	-42.423
ARELAS	-16.466	288.507	2452.000	0.050	172.844
HOPLAS	31.684	249.122	2383.000	0.092	13.541
QUNC76	39.973	239.060	1087.000	0.131	28.340
SAN076	32.601	243.159	1025.000	0.150	14.773
STALAS	39.020	283.172	56.000	0.050	2.123
BDALAS	32.352	295.344	13.000	0.078	6.955
7082ML0104	41.934	248.573	1980.000	0.077	24.157
KOOTWK	52.178	5.810	85.000	0.016	-38.934
GOLDSTONE	35.424	243.114	1000.000	0.116	20.129
OWENS VAL	37.232	241.705	1207.000	0.117	23.283
WESTFORD	42.622	288.512	124.000	0.056	-2.090
GRND TURK	21.460	0.868	28.000	0.024	4.151
HALEAKELA	20.710	203.741	3048.000	0.106	47.399
RAMLAS	28.227	279.394	10.000	0.047	16.844
SAMOA	-14.340	189.275	15.000	0.051	-151.206
MCDONALD	30.677	255.984	1983.000	0.066	10.089
YARRAGADEE	-29.083	115.417	200.000	0.129	-2.572
FINLAND	60.217	24.394	69.000	0.011	-110.825
KWAJALEIN	9.400	167.500	10.000	0.132	-165.261
GREECE	38.078	23.933	503.000	0.006	-48.847
GRASSE	43.755	6.921	1300.000	0.008	4.889
TLRJPL	34.206	241.828	475.000	0.144	17.920
SHOLAS				0.228	-155.20

TABLE 9

MF HEIGHT DISPLACEMENT AMPLITUDES AND PHASES

STATION	LAT (DEG)	LON (DEG)	HT (M)	AMP (CM)	PHASE (DEG)
ORRLAS	-35.625	148.955	929.000	0.015	-14.986
NATLAS	-5.928	324.835	46.000	0.115	-168.898
WETZEL	49.146	12.878	663.000	0.049	6.234
ARELAS	-16.466	288.507	2452.000	0.046	-177.287
HOPLAS	31.684	249.122	2383.000	0.013	-142.402
QUN076	39.973	239.060	1087.000	0.027	-20.695
SAN076	32.601	243.159	1025.000	0.016	-104.526
STALAS	39.020	283.172	56.000	0.021	17.833
BDALAS	32.352	295.344	13.000	0.033	-72.979
7082ML0104	41.934	248.579	1980.000	0.019	-0.424
KOOTWK	52.178	5.810	85.000	0.078	2.250
GOLDSTONE	35.424	243.114	1000.000	0.011	-65.480
OWENS VAL	37.232	241.705	1207.000	0.015	-38.443
WESTFORD	42.622	288.512	124.000	0.043	12.043
GRND TURK	21.460	0.868	28.000	0.021	-140.298
HALEAKELA	20.710	203.741	3048.000	0.056	-143.445
RAMLAS	28.227	279.394	10.000	0.037	144.444
SAMOA	-14.340	189.275	15.000	0.091	-163.423
MCDONALD	30.677	255.984	1983.000	0.036	-115.212
YARRAGADEE	-29.083	115.417	200.000	0.011	-130.066
FINLAND	60.217	24.394	69.000	0.068	19.867
KWAJALEIN	9.400	167.500	10.000	0.098	-162.408
GREECE	38.078	23.933	503.000	0.018	3.649
GRASSE	43.755	6.921	1300.000	0.040	-4.266
TLRJPL	34.206	241.828	475.000	0.014	-81.189
SHOLAS				0.021	-26.86

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C      SUBROUTINE ARG(IYEAR, DAY, ANGLE)
C
C      COMPUTES THE ANGULAR ARGUMENT WHICH DEPENDS ON TIME FOR 11
C      TIDAL ARGUMENT CALCULATIONS
C
C      ORDER OF THE 11 ANGULAR QUANTITIES IN VECTOR ANGLE
C
C      01-M2
C      02-S2
C      03-N2
C      04-K2
C      05-K1
C      06-O1
C      07-P1
C      08-Q1
C      09-MF
C      10-MM
C      11-SSA
C
C      TAKEN FROM 'TABLE 1 CONSTANTS OF MAJOR TIDAL MODES'
C      WHICH DR. SCHWIDERSKI SENDS ALONG WITH HIS TAPE OF TIDAL
C      AMPLITUDES AND PHASES
C
C      INPUT--
C
C      IYEAR -   EX. 79 FOR 1979
C      DAY -   DAY OF YEAR GREENWICH TIME
C              EXAMPLE 32.5 FOR FEB 1 12 NOON
C                   1.25 FOR JAN 1 6 AM
C
C      OUTPUT--
C
C      ANGLE -   ANGULAR ARGUMENT FOR SCHWIDERSKI COMPUTATION
C
C*****
C
C      C A U T I O N
C
C      SCHWIDERSKI MODIFIES THE ANGULAR ARGUMENTS OF THE DIURNAL
C      TERMS BY +/- 90 DEGREES. THEREFORE HIS DIURNAL PHASES
C      CANNOT BE USED WITH THE STANDARD DOODSON OR CARTWRIGHT
C      CONVENTIONS
C
C*****
C

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SUBROUTINE ARG(IYEAR, DAY, ANGLE)
IMPLICIT DOUBLE PRECISION (A-H, O-Z)
REAL ANCFAC(4, 11)
DIMENSION ANGLE(11), SPEED(11)
C SPEED OF ALL TERMS IN RADIANS PER SEC
EQUIVALENCE (SPEED(1), SIGM2), (SPEED(2), SIGS2), (SPEED(3), SIGN2)
EQUIVALENCE (SPEED(4), SICK2), (SPEED(5), SICK1), (SPEED(6), SIGO1)
EQUIVALENCE (SPEED(7), SIGP1), (SPEED(8), SIGQ1), (SPEED(9), SIGMF)
EQUIVALENCE (SPEED(10), SIGMM), (SPEED(11), SIGSSA)
DATA SIGM2/1.40519D-4/
DATA SIGS2/1.45444D-4/
DATA SIGN2/1.37880D-4/
DATA SICK2/1.45842D-4/
DATA SICK1/.72921D-4/
DATA SIGO1/.67598D-4/
DATA SIGP1/.72523D-4/
DATA SIGQ1/.64959D-4/
DATA SIGMF/.053234D-4/
DATA SIGMM/.026392D-4/
DATA SIGSSA/.003982D-4/
DATA ANCFAC/2.E0, -2.E0, 0.E0, 0.E0, 4*0.E0,
.      2.E0, -3.E0, 1.E0, 0.E0, 2.E0, 3*0.E0,
.      1.E0, 2*0.E0, .25E0, 1.E0, -2.E0, 0.E0, -.25E0,
.      -1.E0, 2*0.E0, -.25E0, 1.E0, -3.E0, 0.E0, -.25E0,
.      0.E0, 2.E0, 2*0.E0, 0.E0, 1.E0, -1.E0, 0.E0,
.      2.E0, 3*0.E0/
DATA TWOPI/6.28318530718D0/
DATA DTR/.174532925199D-1/
C DAY OF YEAR
ID=DAY
C FRACTIONAL PART OF DAY IN SECONDS
FDAY=(DAY-ID)*86400.D0
ICAPD=ID+365*(IYEAR-75)+((IYEAR-75)/4)
CAPT=(27392.500528D0+1.000000035D0*ICAPD)/86525.D0
C MEAN LONGITUDE OF SUN AT BEGINNING OF DAY
H0=(279.69668D0+(36000.768930485D0+8.03D-4*CAPT)*CAPT)*DTR
C MEAN LONGITUDE OF MOON AT BEGINNING OF DAY
S0=((1.9D-6*CAPT-.001133D0)*CAPT+481267.88814187D0)*CAPT
.      +270.434358D0)*DTR
C MEAN LONGITUDE OF LUNAR PERIGEE AT BEGINNING OF DAY
P0=(((-1.2D-5*CAPT-.010325D0)*CAPT+4069.0340329577D0)*CAPT
.      +334.329653D0)*DTR
DO 500 K=1, 11
ANGLE(K)=SPEED(K)*FDAY+ANGFAC(1, K)*H0+ANGFAC(2, K)*S0
.      +ANGFAC(3, K)*P0+ANGFAC(4, K)*TWOPI
ANGLE(K)=DMOD(ANGLE(K), TWOPI)
IF (ANGLE(K).LT.0.D0) ANGLE(K)=ANGLE(K)+TWOPI
500 CONTINUE
RETURN
END

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The latitude and time variations resulting from the deflections of local vertical due to the ocean-tide loading have been compiled by T. Sasao, T. Sato and I. Kikuchi of the IPMS/ILO, Mizusawa, Japan. Amplitude and phase of the latitude and time variations for 67 IPMS stations have been computed for the M2, S2, K1, O1, N2, P1, K2, Q1, and Mf ocean tides using models generated by Schwiderski (1978). The technique of Sasao and Sato (1981) which used Green's function for the deflections of the vertical constructed from Farrell's (1972) load deformation coefficients was employed. For the majority of stations, the ocean-induced latitude and time variations are less than one milliarcsecond. However, for the Greenwich, San Fernando and Rio Grande stations, the ocean effects exceed 10 milliarcseconds.

Tables 1-12 give the amplitude and phase values for the nine models. Both the latitude and time variations can be found for a given component i as follows:

$$d(i) = \text{amp}(i) \cdot \cos(\arg(i, t) - \text{phase}(i)).$$

The argument $\arg(i, t)$ is calculated by the following formulase:

component	argument
M2	$2t_G - 2L_\Delta$
S2	$2t_G - 2L_\odot$
K1	$t_G - 90^\circ$
O1	$t_G - 2L_\Delta + 90^\circ$
N2	$2t_G - 3L_\Delta + \Gamma'$
P1	$t_G - 2L_\odot + 90^\circ$
K2	$2t_G$
Q1	$t_G - 3L_\Delta + \Gamma'$
Mf	$2L_\Delta$

where t_G , L_Δ , $L_\odot$, and Γ' are Greenwich mean sidereal time, mean longitude of the Moon, mean longitude of the Sun and mean longitude of lunar perigee, respectively.

REFERENCES

- Farrell, W. E., 1972 : Deformation of the earth by surface loads. - Rev. Geophys. Space Phys., 10 : 761-797.
- Schwiderski, E. W., 1980 : On charting global ocean tides. - Rev. Geophys. Space Phys., 18 : 243-268.
- Schwiderski, E. W., 1981 : NSWC global ocean tide data tape.
- Sasao, T. & Sato, T., 1983 : Effects of ocean tides upon astronomical time and latitude observations. - Proceedings of the ninth international symposium on earth tides, held in New York, 1981.

Ocean-Tide Loading Effects upon Astronomical Observations 1
(Amplitude in Milliarcsecond and Phase in Degree)

Mizusawa	Latitude		39.134	East Longitude		141.131			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	1.080	0.487	0.649	0.468	0.209	0.197	0.139	0.096	0.043
Phase	248.7	271.5	61.5	44.8	243.5	60.7	276.9	28.3	44.9
Time									
Amplitude	2.237	0.990	1.879	1.548	0.274	0.585	0.265	0.323	0.026
Phase	359.9	41.6	198.1	178.5	341.5	197.3	39.5	174.4	330.7
Kitab	Latitude		39.133	East Longitude		66.881			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.273	0.116	0.190	0.091	0.073	0.057	0.032	0.021	0.020
Phase	155.8	188.9	359.1	6.8	147.4	357.4	186.7	358.8	8.9
Time									
Amplitude	0.050	0.037	0.060	0.033	0.005	0.021	0.011	0.005	0.002
Phase	23.8	77.6	343.9	322.5	6.1	344.4	93.2	276.7	213.0
Carloforte	Latitude		39.136	East Longitude		8.312			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.355	0.115	0.064	0.028	0.066	0.017	0.027	0.014	0.029
Phase	309.9	354.0	16.9	138.8	286.3	9.3	358.2	121.9	351.5
Time									
Amplitude	0.747	0.272	0.047	0.057	0.153	0.015	0.075	0.020	0.018
Phase	79.9	107.6	127.3	282.1	59.1	100.6	104.5	242.2	129.4
Gaithersburg	Latitude		39.137	East Longitude		282.801			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	1.156	0.205	0.191	0.146	0.229	0.055	0.053	0.032	0.031
Phase	353.8	26.7	174.7	185.1	337.5	171.6	20.4	184.6	339.1
Time									
Amplitude	2.298	0.474	0.383	0.284	0.499	0.114	0.131	0.060	0.040
Phase	178.9	210.3	350.7	0.2	160.9	349.9	205.6	0.4	6.1
Ukiah	Latitude		39.137	East Longitude		236.790			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	1.730	0.745	1.333	0.832	0.425	0.375	0.236	0.152	0.035
Phase	129.9	130.2	201.9	187.0	108.9	203.9	132.2	176.2	40.6
Time									
Amplitude	4.540	0.996	3.303	2.044	0.936	0.949	0.323	0.368	0.110
Phase	224.3	255.7	232.4	219.6	193.4	233.1	242.4	211.6	146.4
Blagovestchensk	Latitude		50.319	East Longitude		127.479			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.261	0.116	0.083	0.062	0.051	0.023	0.038	0.011	0.020
Phase	230.0	269.9	88.8	101.7	232.2	104.4	280.7	58.3	23.0
Time									
Amplitude	0.122	0.093	0.375	0.342	0.003	0.123	0.022	0.070	0.017
Phase	25.0	68.8	219.3	193.8	114.8	220.4	74.3	193.1	9.7

Ocean-Tide Loading Effects upon Astronomical Observations 2
(Amplitude in Milliarcsecond and Phase in Degree)

Tianjin									
	Latitude		39.134	East Longitude		117.054			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.562	0.218	0.314	0.216	0.073	0.087	0.074	0.030	0.013
Phase	234.7	295.7	93.8	79.1	256.6	129.1	308.3	90.3	348.6
Time									
Amplitude	1.121	0.393	0.529	0.382	0.158	0.072	0.121	0.041	0.016
Phase	43.4	100.7	215.8	181.4	58.7	245.7	117.2	198.1	24.2
Borowiec									
	Latitude		52.277	East Longitude		17.077			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.218	0.100	0.108	0.011	0.049	0.033	0.031	0.020	0.045
Phase	81.6	114.5	33.6	243.6	69.0	36.5	117.3	176.8	37.7
Time									
Amplitude	0.406	0.144	0.077	0.017	0.076	0.021	0.036	0.013	0.035
Phase	113.9	144.5	155.1	301.6	99.3	137.9	141.7	256.7	167.0
Irkutsk									
	Latitude		52.279	East Longitude		104.345			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.036	0.025	0.089	0.072	0.014	0.027	0.008	0.013	0.018
Phase	206.7	235.0	102.9	105.4	186.8	113.7	251.3	87.2	18.8
Time									
Amplitude	0.107	0.062	0.080	0.072	0.019	0.027	0.019	0.017	0.005
Phase	63.9	101.5	246.2	208.9	93.2	247.6	116.1	202.8	358.4
Engelhardt									
	Latitude		55.839	East Longitude		48.816			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.052	0.032	0.098	0.031	0.020	0.025	0.010	0.005	0.023
Phase	87.6	139.2	50.3	58.8	120.4	52.2	130.4	100.4	25.7
Time									
Amplitude	0.093	0.048	0.029	0.012	0.015	0.006	0.013	0.005	0.009
Phase	32.8	75.6	206.0	242.9	358.8	207.9	87.1	221.7	189.6
Gorky									
	Latitude		56.259	East Longitude		43.983			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.056	0.034	0.100	0.026	0.020	0.026	0.011	0.006	0.025
Phase	81.4	133.3	51.1	61.6	113.8	53.0	123.2	120.2	26.9
Time									
Amplitude	0.100	0.050	0.037	0.011	0.016	0.009	0.014	0.006	0.012
Phase	38.2	78.9	194.1	245.0	3.5	189.8	87.7	229.3	186.5
Poltava									
	Latitude		49.604	East Longitude		34.550			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.054	0.035	0.088	0.022	0.017	0.024	0.012	0.006	0.021
Phase	76.3	120.8	39.4	59.0	108.6	37.3	120.6	104.3	15.4
Time									
Amplitude	0.119	0.056	0.045	0.020	0.020	0.011	0.016	0.008	0.012
Phase	62.4	94.3	182.6	234.3	36.3	174.6	96.7	216.3	173.8

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Ocean-Tide Loading Effects upon Astronomical Observations 3
(Amplitude in Milliarcsecond and Phase in Degree)

Pulkovo									
	Latitude		59.771	East Longitude		30.327			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.126	0.055	0.099	0.033	0.039	0.021	0.017	0.010	0.020
Phase	119.2	158.9	68.6	79.6	110.4	69.6	147.4	192.0	21.3
Time									
Amplitude	0.124	0.063	0.033	0.035	0.013	0.013	0.020	0.003	0.014
Phase	22.1	77.0	157.9	262.4	346.5	125.8	66.6	73.2	143.8
Warsaw									
	Latitude		52.099	East Longitude		21.036			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.142	0.071	0.094	0.007	0.036	0.025	0.023	0.012	0.032
Phase	79.1	112.8	35.8	168.8	78.3	31.0	111.4	145.6	19.3
Time									
Amplitude	0.288	0.105	0.066	0.016	0.052	0.018	0.027	0.011	0.027
Phase	105.3	134.8	163.0	287.7	90.2	148.3	131.7	252.9	168.8
Belgrade									
	Latitude		44.803	East Longitude		20.513			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.097	0.045	0.076	0.014	0.012	0.021	0.014	0.009	0.023
Phase	10.7	69.6	35.4	96.5	15.4	31.2	81.5	121.9	6.0
Time									
Amplitude	0.305	0.116	0.049	0.028	0.058	0.012	0.032	0.011	0.015
Phase	89.1	117.1	166.2	258.2	68.3	150.2	114.2	229.3	155.8
Pecny									
	Latitude		49.916	East Longitude		14.788			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.221	0.100	0.092	0.010	0.047	0.025	0.031	0.012	0.037
Phase	55.2	92.7	31.9	218.3	48.0	26.0	96.3	149.1	14.1
Time									
Amplitude	0.536	0.189	0.071	0.027	0.103	0.020	0.048	0.014	0.033
Phase	109.0	139.4	149.3	293.7	92.6	131.1	135.9	253.8	160.9
Dresden									
	Latitude		51.054	East Longitude		13.733			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.275	0.119	0.098	0.016	0.061	0.027	0.037	0.013	0.042
Phase	65.8	100.3	31.6	233.3	55.5	25.0	102.2	152.9	16.1
Time									
Amplitude	0.572	0.201	0.077	0.024	0.112	0.022	0.050	0.014	0.040
Phase	115.1	145.4	147.6	299.3	99.5	129.2	142.0	256.2	163.1
La Plata									
	Latitude		34.909	East Longitude		302.068			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.388	0.206	0.147	1.081	0.174	0.133	0.105	0.375	0.080
Phase	355.2	90.1	189.8	80.8	84.4	206.3	111.9	59.0	63.6
Time									
Amplitude	0.989	0.118	0.208	0.295	0.299	0.041	0.071	0.024	0.113
Phase	90.5	352.1	351.2	315.3	106.3	292.5	334.2	8.4	52.4

Ocean-Tide Loading Effects upon Astronomical Observations 4
(Amplitude in Milliarcsecond and Phase in Degree)

Churel Togot	Latitude	47.866	East Longitude	107.050					
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.034	0.025	0.097	0.088	0.012	0.031	0.009	0.015	0.016
Phase	234.8	250.6	116.3	115.0	207.5	125.9	270.7	96.5	14.2
Time									
Amplitude	0.145	0.079	0.095	0.083	0.029	0.032	0.025	0.020	0.006
Phase	69.2	105.3	249.4	214.7	93.1	250.9	118.8	207.1	359.5
Potsdam	Latitude	52.382	East Longitude	13.067					
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.355	0.131	0.126	0.017	0.082	0.031	0.042	0.017	0.051
Phase	93.2	118.5	42.2	240.6	73.7	29.3	119.4	168.9	28.3
Time									
Amplitude	0.474	0.197	0.076	0.027	0.093	0.026	0.047	0.018	0.051
Phase	114.0	143.5	144.7	294.1	103.1	117.3	140.1	239.6	158.2
Dehra Dun	Latitude	30.315	East Longitude	78.050					
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.399	0.170	0.188	0.078	0.100	0.058	0.047	0.023	0.030
Phase	142.9	180.8	342.3	0.2	136.2	341.6	179.5	1.1	9.8
Time									
Amplitude	0.252	0.082	0.277	0.150	0.058	0.089	0.023	0.028	0.003
Phase	195.8	225.1	349.8	343.0	178.0	350.2	212.9	329.9	347.5
Milano-Brera	Latitude	45.467	East Longitude	9.191					
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.299	0.124	0.082	0.014	0.059	0.022	0.034	0.013	0.038
Phase	5.2	49.7	22.4	194.2	355.0	16.3	58.6	145.8	4.0
Time									
Amplitude	0.982	0.344	0.080	0.060	0.194	0.025	0.091	0.021	0.032
Phase	97.2	128.3	127.6	300.3	78.5	108.5	125.3	257.6	144.3
Sodankyla	Latitude	67.368	East Longitude	26.633					
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.609	0.208	0.238	0.029	0.143	0.064	0.050	0.036	0.082
Phase	232.6	257.6	66.0	229.5	190.9	71.0	259.3	183.3	55.5
Time									
Amplitude	1.249	0.402	0.212	0.077	0.242	0.070	0.112	0.024	0.067
Phase	348.0	27.8	153.3	37.2	316.7	144.2	23.9	315.8	200.2
Mt. Stromlo	Latitude	- 35.322	East Longitude	149.005					
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	1.222	0.223	0.625	0.495	0.205	0.215	0.071	0.114	0.059
Phase	359.0	67.0	256.1	233.2	326.2	257.9	70.4	227.4	202.2
Time									
Amplitude	2.889	0.924	0.843	0.465	0.562	0.259	0.256	0.102	0.023
Phase	115.6	136.1	178.7	151.9	106.6	175.5	134.6	129.7	259.1

Ocean-Tide Loading Effects upon Astronomical Observations 5
(Amplitude in Milliarcsecond and Phase in Degree)

Tokyo									
	Latitude 35.672			East Longitude 139.541					
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	2.491	1.136	1.435	1.063	0.462	0.454	0.322	0.206	0.050
Phase	256.2	279.4	57.4	35.4	253.7	56.5	282.9	23.4	63.1
Time									
Amplitude	2.240	0.993	1.474	1.209	0.330	0.460	0.258	0.254	0.022
Phase	2.2	41.7	197.8	175.6	347.7	197.0	42.3	170.2	329.1
Neuchatel									
	Latitude 46.998			East Longitude 6.958					
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.421	0.177	0.092	0.022	0.095	0.025	0.051	0.013	0.046
Phase	30.8	68.6	22.5	245.2	18.9	17.4	75.7	164.7	7.3
Time									
Amplitude	1.313	0.456	0.110	0.078	0.256	0.035	0.118	0.026	0.043
Phase	101.5	134.1	121.1	310.8	84.1	104.5	131.2	266.4	145.7
Washington									
	Latitude 38.921			East Longitude 282.934					
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	1.053	0.194	0.180	0.141	0.207	0.053	0.048	0.032	0.031
Phase	350.8	22.8	175.6	184.0	335.4	171.0	24.1	184.5	337.7
Time									
Amplitude	1.774	0.417	0.336	0.260	0.387	0.109	0.109	0.058	0.042
Phase	168.9	201.1	350.9	356.6	154.1	347.3	213.2	358.2	7.5
Richmond									
	Latitude 25.613			East Longitude 279.618					
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.382	0.065	0.264	0.267	0.141	0.090	0.005	0.056	0.100
Phase	147.6	41.4	318.0	322.0	138.8	355.8	23.0	322.2	337.9
Time									
Amplitude	4.485	0.796	1.100	0.900	0.996	0.338	0.186	0.190	0.052
Phase	190.0	215.5	32.0	28.5	169.1	29.3	217.1	25.7	121.0
Turku									
	Latitude 60.416			East Longitude 22.446					
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.297	0.129	0.148	0.018	0.099	0.034	0.039	0.019	0.031
Phase	145.1	165.5	34.9	268.1	119.9	32.3	146.5	134.5	11.4
Time									
Amplitude	0.137	0.027	0.124	0.063	0.008	0.041	0.008	0.020	0.067
Phase	323.8	66.2	158.1	25.4	271.1	162.8	62.5	311.3	203.4
Greenwich									
	Latitude 50.872			East Longitude 0.337					
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	12.917	3.758	0.691	0.388	2.733	0.168	1.204	0.076	0.016
Phase	327.2	9.0	101.5	342.4	283.6	74.4	8.8	3.4	218.7
Time									
Amplitude	9.440	2.614	0.443	0.352	1.609	0.157	0.697	0.156	0.066
Phase	155.1	198.8	136.3	338.2	116.1	128.2	203.4	299.8	149.8

Ocean-Tide Loading Effects upon Astronomical Observations 6
(Amplitude in Milliarcsecond and Phase in Degree)

Ottawa-Shirley Latitude 45.400 East Longitude 284.080									
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.642	0.135	0.104	0.099	0.151	0.031	0.030	0.024	0.022
Phase	8.5	51.4	160.3	183.7	354.9	157.1	46.1	177.2	354.9
Time									
Amplitude	0.963	0.238	0.140	0.087	0.218	0.042	0.067	0.019	0.030
Phase	192.1	223.1	326.4	341.3	168.1	324.0	217.9	343.7	358.7
Calgary Latitude 50.873 East Longitude 245.710									
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.262	0.059	0.300	0.194	0.064	0.089	0.022	0.037	0.020
Phase	175.1	153.9	207.1	192.9	144.3	204.2	147.5	180.6	29.2
Time									
Amplitude	1.193	0.375	0.719	0.445	0.221	0.222	0.100	0.079	0.026
Phase	247.1	288.9	251.5	238.7	220.1	250.3	282.9	234.7	155.4
Punta Indio Latitude - 35.345 East Longitude 302.713									
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.796	0.262	0.299	0.699	0.199	0.107	0.085	0.219	0.031
Phase	320.2	59.8	140.4	69.6	308.9	149.2	81.5	51.7	145.1
Time									
Amplitude	1.475	0.466	0.239	1.119	0.214	0.127	0.279	0.322	0.061
Phase	143.1	311.5	36.0	277.7	182.9	50.3	312.9	248.0	85.1
Moscow Gaish Latitude 55.699 East Longitude 37.542									
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.064	0.039	0.099	0.019	0.023	0.026	0.013	0.007	0.026
Phase	89.5	132.5	48.5	67.0	110.4	49.1	123.3	133.1	26.2
Time									
Amplitude	0.109	0.051	0.047	0.010	0.016	0.012	0.014	0.007	0.015
Phase	50.3	87.5	183.0	253.1	18.1	174.5	92.2	237.9	182.0
Prague Aicas Latitude 49.915 East Longitude 14.786									
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.221	0.100	0.092	0.010	0.047	0.025	0.031	0.012	0.037
Phase	55.2	92.7	31.9	218.3	48.0	26.0	96.2	149.1	14.1
Time									
Amplitude	0.536	0.189	0.071	0.027	0.103	0.020	0.048	0.014	0.033
Phase	109.0	139.4	149.3	293.7	92.5	131.1	135.9	253.8	160.9
Shaanxi Latitude 34.945 East Longitude 109.551									
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.151	0.034	0.178	0.179	0.018	0.060	0.007	0.030	0.020
Phase	15.7	52.3	149.8	135.0	25.0	151.7	53.0	116.3	11.4
Time									
Amplitude	0.330	0.165	0.192	0.152	0.083	0.064	0.057	0.032	0.006
Phase	95.2	126.3	272.9	248.9	109.2	275.6	134.6	236.3	18.7

Ocean-Tide Loading Effects upon Astronomical Observations 7
(Amplitude in Milliarcsecond and Phase in Degree)

Novosibirsk	Latitude		55.030	East Longitude		82.909			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.048	0.028	0.077	0.048	0.020	0.020	0.008	0.008	0.020
Phase	134.2	182.8	69.9	83.2	145.8	77.9	184.2	71.0	21.5
Time									
Amplitude	0.071	0.043	0.034	0.019	0.008	0.012	0.013	0.006	0.002
Phase	46.7	91.7	294.1	247.4	61.2	296.9	108.7	217.7	301.5
Poltava	Latitude		49.604	East Longitude		34.550			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.054	0.035	0.088	0.022	0.017	0.024	0.012	0.006	0.021
Phase	76.3	120.8	39.4	59.0	108.6	37.3	120.6	104.3	15.4
Time									
Amplitude	0.119	0.056	0.045	0.020	0.020	0.011	0.016	0.008	0.012
Phase	62.4	94.3	182.6	234.3	36.3	174.6	96.7	216.3	173.8
Besancon	Latitude		47.249	East Longitude		5.988			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.487	0.204	0.096	0.028	0.115	0.026	0.059	0.014	0.050
Phase	38.2	73.9	21.8	254.4	25.1	17.5	80.8	172.6	8.0
Time									
Amplitude	1.486	0.516	0.125	0.090	0.288	0.040	0.133	0.029	0.047
Phase	102.2	135.3	118.5	314.0	85.2	102.6	132.5	269.3	145.3
Uccle	Latitude		50.798	East Longitude		4.358			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.634	0.242	0.120	0.188	0.121	0.038	0.066	0.041	0.073
Phase	37.2	74.0	95.0	338.5	18.8	107.5	83.7	296.9	13.8
Time									
Amplitude	1.320	0.452	0.141	0.018	0.211	0.039	0.114	0.005	0.078
Phase	92.4	134.3	111.3	285.6	96.3	89.8	122.9	272.7	159.0
Alger	Latitude		36.802	East Longitude		3.035			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.619	0.202	0.064	0.043	0.124	0.018	0.050	0.019	0.034
Phase	295.6	334.0	359.1	145.0	272.6	349.1	334.2	119.5	344.5
Time									
Amplitude	1.058	0.391	0.055	0.079	0.225	0.021	0.108	0.027	0.020
Phase	69.2	95.1	99.9	286.4	48.5	77.6	92.4	244.0	115.3
Santiago	Latitude -		33.399	East Longitude		289.451			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.549	0.147	0.266	0.255	0.129	0.090	0.050	0.068	0.054
Phase	193.4	148.5	135.3	84.7	137.5	136.0	156.6	60.4	193.7
Time									
Amplitude	2.588	0.800	0.978	0.587	0.580	0.333	0.205	0.128	0.019
Phase	67.8	93.5	41.9	354.0	40.2	39.3	85.9	322.6	228.4

Ocean-Tide Loading Effects upon Astronomical Observations 8
(Amplitude in Milliarcsecond and Phase in Degree)

Paris									
	Latitude		48.836	East Longitude		2.337			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	1.531	0.536	0.118	0.086	0.389	0.030	0.162	0.028	0.075
Phase	92.2	120.3	19.2	283.8	64.0	24.0	125.2	222.2	13.6
Time									
Amplitude	1.874	0.614	0.259	0.181	0.353	0.082	0.145	0.052	0.079
Phase	120.1	156.5	116.5	333.6	109.0	104.4	156.9	291.9	149.6
Quito									
	Latitude -		0.216	East Longitude		281.251			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	2.971	0.709	0.144	0.165	0.611	0.059	0.164	0.037	0.032
Phase	61.5	130.9	11.1	6.9	33.0	15.4	130.8	357.2	195.9
Time									
Amplitude	4.313	1.273	0.599	0.102	0.944	0.177	0.364	0.017	0.076
Phase	251.7	304.0	49.7	43.5	223.8	52.3	303.5	118.3	19.4
San Fernando									
	Latitude		36.462	East Longitude		353.795			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	2.644	1.144	0.493	0.312	0.864	0.147	0.309	0.090	0.077
Phase	21.0	52.1	37.1	314.2	2.6	29.3	55.0	234.4	359.2
Time									
Amplitude	12.858	4.727	0.808	0.749	2.947	0.263	1.301	0.217	0.075
Phase	65.4	86.6	47.8	317.5	41.3	40.1	87.2	253.6	75.4
San Juan									
	Latitude -		31.511	East Longitude		291.380			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.264	0.154	0.227	0.232	0.081	0.075	0.048	0.061	0.048
Phase	171.6	124.0	120.7	75.4	105.0	120.8	133.2	53.3	196.8
Time									
Amplitude	1.573	0.435	0.625	0.369	0.342	0.214	0.110	0.081	0.010
Phase	59.8	84.8	38.6	346.7	33.4	36.8	72.1	316.0	252.5
San Martin									
	Latitude -		34.574	East Longitude		301.481			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.337	0.123	0.115	0.744	0.059	0.044	0.045	0.202	0.047
Phase	252.9	47.7	126.1	86.0	94.4	147.0	80.4	53.2	174.0
Time									
Amplitude	1.253	0.154	0.381	0.241	0.511	0.104	0.080	0.082	0.085
Phase	130.7	299.7	323.1	96.4	110.8	299.9	314.9	38.9	72.7
Simeiz									
	Latitude		44.403	East Longitude		33.997			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.045	0.031	0.086	0.027	0.012	0.024	0.011	0.006	0.017
Phase	61.5	113.1	34.6	51.0	113.8	31.7	117.7	76.8	7.5
Time									
Amplitude	0.121	0.058	0.049	0.027	0.023	0.012	0.017	0.010	0.009
Phase	52.5	86.0	182.3	221.2	25.1	176.3	88.9	202.0	170.5

Ocean-Tide Loading Effects upon Astronomical Observations 9
(Amplitude in Milliarcsecond and Phase in Degree)

Nikolaiev	Latitude		46.972	East	Longitude		31.974		
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.051	0.034	0.085	0.022	0.013	0.023	0.011	0.006	0.019
Phase	59.0	110.2	37.6	59.8	103.2	34.8	114.0	98.9	11.1
Time									
Amplitude	0.133	0.061	0.047	0.023	0.024	0.012	0.018	0.009	0.011
Phase	66.7	96.9	181.0	231.4	41.3	172.9	98.0	212.1	169.6
Leningrad	Latitude		59.918	East	Longitude		30.316		
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.125	0.055	0.099	0.034	0.039	0.021	0.017	0.010	0.020
Phase	119.7	159.4	71.3	85.8	110.8	73.0	148.5	196.7	18.9
Time									
Amplitude	0.118	0.076	0.042	0.092	0.006	0.023	0.028	0.018	0.037
Phase	9.8	78.7	15.8	254.2	325.6	53.6	61.8	103.2	68.4
Bucarest	Latitude		44.414	East	Longitude		26.096		
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.063	0.035	0.078	0.019	0.007	0.021	0.011	0.007	0.020
Phase	23.8	86.5	37.2	72.8	67.1	33.9	96.7	107.0	6.4
Time									
Amplitude	0.189	0.079	0.048	0.026	0.035	0.012	0.023	0.010	0.012
Phase	78.4	106.2	176.4	238.8	55.1	165.9	104.9	215.8	161.5
Borowa Gora	Latitude		52.483	East	Longitude		21.037		
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.147	0.073	0.095	0.008	0.037	0.025	0.024	0.012	0.033
Phase	82.5	115.2	35.8	175.1	80.4	31.0	113.1	146.7	20.1
Time									
Amplitude	0.284	0.103	0.068	0.016	0.051	0.018	0.027	0.011	0.028
Phase	106.1	135.7	163.0	291.6	91.5	148.4	132.7	254.8	169.5
Bratislava	Latitude		48.155	East	Longitude		17.120		
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.150	0.072	0.085	0.007	0.029	0.023	0.023	0.011	0.031
Phase	38.5	82.8	33.1	153.7	38.3	27.9	89.3	139.8	11.2
Time									
Amplitude	0.437	0.157	0.060	0.027	0.083	0.016	0.041	0.013	0.024
Phase	101.1	130.6	155.0	280.6	83.0	137.1	127.1	245.8	158.7
Roma	Latitude		41.922	East	Longitude		12.452		
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.214	0.075	0.070	0.018	0.035	0.019	0.019	0.012	0.027
Phase	332.8	24.3	26.5	133.0	312.4	20.6	35.3	126.0	358.5
Time									
Amplitude	0.590	0.214	0.050	0.044	0.118	0.014	0.058	0.016	0.019
Phase	87.4	116.1	143.0	279.0	66.8	119.2	112.9	241.1	141.0

Ocean-Tide Loading Effects upon Astronomical Observations 10
(Amplitude in Milliarcsecond and Phase in Degree)

Torino									
	Latitude	45.039	East Longitude		7.777				
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.347	0.141	0.083	0.018	0.068	0.023	0.038	0.014	0.039
Phase	358.0	42.5	18.5	192.9	347.5	12.0	51.0	145.9	2.4
Time									
Amplitude	1.160	0.406	0.088	0.071	0.231	0.028	0.107	0.024	0.034
Phase	96.4	127.6	121.9	302.8	77.4	103.6	124.8	259.6	141.3
Shanghai									
	Latitude	31.190	East Longitude		121.428				
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	3.751	1.534	1.095	0.671	0.603	0.368	0.389	0.102	0.030
Phase	359.0	41.0	106.7	81.1	348.2	98.0	36.5	83.1	58.3
Time									
Amplitude	2.822	1.066	1.986	1.354	0.779	0.600	0.299	0.237	0.063
Phase	245.9	294.4	259.8	224.9	228.6	262.0	289.0	226.9	98.8
Beijing									
	Latitude	40.101	East Longitude		116.328				
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.201	0.096	0.203	0.197	0.058	0.069	0.039	0.035	0.014
Phase	270.5	300.8	129.2	117.1	283.3	134.7	313.7	101.4	356.7
Time									
Amplitude	0.432	0.197	0.184	0.164	0.100	0.059	0.067	0.036	0.012
Phase	59.1	99.0	250.1	225.7	80.8	253.6	117.6	216.4	16.4
Wuchang									
	Latitude	30.541	East Longitude		114.345				
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.452	0.130	0.340	0.324	0.054	0.110	0.028	0.055	0.030
Phase	8.2	37.0	154.4	134.3	7.1	153.3	42.8	116.1	16.2
Time									
Amplitude	0.553	0.257	0.408	0.320	0.141	0.131	0.089	0.066	0.008
Phase	124.8	145.6	266.1	242.8	127.5	268.9	148.7	234.6	47.5
Prague Oagtu									
	Latitude	50.078	East Longitude		14.420				
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.234	0.104	0.093	0.011	0.050	0.025	0.033	0.012	0.039
Phase	56.6	93.5	31.8	223.6	48.6	25.7	96.9	150.2	14.3
Time									
Amplitude	0.553	0.194	0.072	0.027	0.107	0.020	0.049	0.014	0.034
Phase	110.1	140.5	148.4	295.1	93.7	130.2	137.0	254.5	161.1
Irkutsk Astr.									
	Latitude	52.279	East Longitude		104.345				
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.036	0.025	0.089	0.072	0.014	0.027	0.008	0.013	0.018
Phase	206.7	235.0	102.9	105.4	186.8	113.7	251.3	87.2	18.8
Time									
Amplitude	0.107	0.062	0.080	0.072	0.019	0.027	0.019	0.017	0.005
Phase	63.9	101.5	246.2	208.9	93.2	247.6	116.1	202.8	358.4

Ocean-Tide Loading Effects upon Astronomical Observations 11
(Amplitude in Milliarcsecond and Phase in Degree)

Tachkent									
	Latitude		41.325	East Longitude		69.294			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.210	0.092	0.141	0.066	0.058	0.042	0.026	0.016	0.019
Phase	151.7	185.9	5.3	16.0	145.1	3.0	184.1	6.4	9.3
Time									
Amplitude	0.042	0.034	0.062	0.034	0.003	0.021	0.011	0.005	0.002
Phase	35.3	84.8	341.2	321.2	38.9	341.8	101.3	278.1	221.8
Mendielievo									
	Latitude		56.029	East Longitude		37.232			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.065	0.039	0.100	0.019	0.023	0.026	0.013	0.007	0.027
Phase	90.0	132.8	49.0	68.2	110.0	49.8	123.0	135.8	26.8
Time									
Amplitude	0.110	0.051	0.048	0.010	0.016	0.012	0.014	0.007	0.015
Phase	50.0	87.5	182.3	256.3	17.4	173.6	92.0	240.5	182.3
Riga									
	Latitude		56.950	East Longitude		24.060			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.227	0.102	0.134	0.021	0.042	0.053	0.032	0.043	0.093
Phase	118.1	151.1	41.8	323.4	99.0	56.4	159.8	201.4	70.1
Time									
Amplitude	0.121	0.045	0.102	0.012	0.026	0.031	0.017	0.024	0.063
Phase	85.7	108.2	178.1	129.3	98.9	202.3	83.2	14.2	239.0
Rio De Janeiro									
	Latitude -		22.895	East Longitude		316.777			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	1.019	0.893	0.470	0.579	0.155	0.146	0.198	0.185	0.063
Phase	92.6	132.8	158.0	94.3	38.1	151.7	142.6	79.1	22.8
Time									
Amplitude	2.775	1.473	0.307	0.618	0.387	0.101	0.423	0.138	0.057
Phase	357.7	8.5	32.7	321.7	6.7	30.1	2.7	300.0	160.5
Buenos Aires									
	Latitude -		34.622	East Longitude		301.645			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	0.460	0.072	0.050	0.953	0.173	0.046	0.034	0.256	0.049
Phase	210.9	37.7	204.3	90.8	110.0	202.0	88.3	54.3	150.9
Time									
Amplitude	1.895	0.242	0.589	0.655	0.774	0.186	0.094	0.191	0.140
Phase	140.1	273.5	306.3	102.6	113.7	280.5	297.2	51.2	70.5
Purple Mountain									
	Latitude		32.067	East Longitude		118.821			
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	1.419	0.448	0.551	0.374	0.131	0.165	0.103	0.072	0.038
Phase	4.0	40.7	116.4	95.9	12.8	113.2	48.5	81.5	17.4
Time									
Amplitude	0.167	0.185	0.656	0.490	0.181	0.201	0.072	0.096	0.029
Phase	108.6	111.6	253.3	233.2	157.6	262.1	132.6	229.2	57.4

Appendix A: General Relativistic Dynamical Corrections

Ocean-Tide Loading Effects upon Astronomical Observations 12
(Amplitude in Milliarcsecond and Phase in Degree)

Rio Grande	Latitude - 53.786		East Longitude 292.249						
Latitude	M2	S2	K1	O1	N2	P1	K2	Q1	Mf
Amplitude	19.388	5.262	1.120	0.704	4.630	0.399	1.729	0.026	0.039
Phase	209.0	261.0	351.8	284.5	180.6	351.8	253.5	20.7	222.2
Time									
Amplitude	15.731	3.489	1.124	1.416	3.353	0.392	1.079	0.145	0.060
Phase	188.9	228.7	310.8	246.0	158.3	312.2	226.1	204.8	348.0

References

Neuhall, L.L., Standish, Jr., E. M., and Williams, J. G., 1983, *Astrophys. J.*, 225, 150-167

Appendix 8: General Relativistic Dynamical Corrections

For LLR, the isotropic Parameterized Post-Newtonian (PPN) N-body metric with $\gamma = \beta = 1$ is used (see e.g., "A Numerically Integrated Ephemeris of the Moon and Planets Spanning 44 Centuries," X. X. Newhall, E. M. Standish, Jr., and J. G. Williams; in press, Astron. Astrophys.) For SLR, only the earth and the sun produce significant relativistic effects. These effects are small compared to other perturbations that are imperfectly modeled; they have little effect on short-term determinations of ERP variability. Inclusion of the relativistic dynamical terms significantly affects the computation times for SLR orbits. Accordingly, the dynamical relativistic terms are omitted in SLR. It should be noted that the adopted GE value is derived from the lunar and planetary ephemeris system which does include the full relativistic formulation for dynamics and for propagation.

References

- Newhall, X.X., Standish, Jr., E. M., and Williams, J. G., 1983, Astron. Astrophys., 125, 150-167

Epoch and Time Intervals

The transformation from Solar System barycentric coordinate time t to proper time $\tau = \text{TAI} + 32.184$ s. involves an annual and diurnal term and other small terms. This transformation has usually been given in the past in terms of the earth's orbital elements, terrestrial coordinates and UT. With the near universal availability of ephemeris tapes, a more convenient expression is given with sufficient accuracy (Moyer, 1981) by

$$\tau - t = \Delta T_A + \frac{2}{c^2} \left(\dot{r}_B^S \cdot \dot{r}_B^S \right) + \frac{1}{c^2} \left(\dot{r}_B^C \cdot \dot{r}_B^C \right) + \frac{1}{c^2} \left(\dot{r}_B^E \cdot \dot{r}_B^E \right) + \frac{r_J^S}{c^2 (\mu_S + \mu_J)} \left(\dot{r}_J^S \cdot \dot{r}_J^S \right) + \frac{r_{SA}^S}{c^2 (\mu_S + \mu_{SA})} \left(\dot{r}_{SA}^S \cdot \dot{r}_{SA}^S \right) + \frac{1}{c^2} \left(\dot{r}_S^C \cdot \dot{r}_S^C \right)$$

where $\Delta T_A = 32.184$ s.

Appendix 2: General Relativistic Dynamical Corrections

For LLR, the isotropic Parameterized Post-Newtonian (PPN) N-body metric with $\gamma = \beta = 1$ is used (see e.g., "A Numerically Integrated Ephemeris of the Moon and Planets Spanning 40 Centuries", E. M. Standish, Jr., and J. G. Williams, in press, Astron. Astrophys.). For SLR, only the earth and the sun produce significant relativistic effects. These effects are small compared to other perturbations that are imperfectly modeled; they have little effect on short-term determinations of ERP variability. Inclusion of the relativistic dynamical terms significantly effects the computation times for SLR orbits. Accordingly, the dynamical relativistic terms are omitted in SLR. It should be noted that the adopted GE value is derived from the lunar and planetary ephemeris system which does include the full relativistic formulation for dynamics and for propagation.

References

- Newhall, X.I., Standish, Jr., E. M., and Williams, J. G., 1983, Astron. Astrophys., 122, 150-167

Appendix 9: General Relativistic Terms for Propagation and Time

Propagation

The space-time curvature near a massive body requires a correction to the euclidean computation of range, ρ . This correction in light-seconds, $\delta\tau$, is given by (Holdridge, 1967)

$$\delta\tau = \frac{2GM}{c^3} \ln \left[\frac{R_1 + R_2 + \rho}{R_1 + R_2 - \rho} \right]$$

where R_1 and R_2 are the distance from the central body to the beginning and end of the light path, respectively, c is the speed of light and GM is the central gravitational constant of the deflecting body. For VLBI observations of distant radio sources this form is unsuitable and should be replaced by the limiting form of the above expression as ρ and $R_2 \rightarrow \infty$. One version for differential delay between two stations is given by

$$\delta\tau_a - \delta\tau_b = \frac{2GM}{c^3} \ln \left[\frac{R_b \cos^2(\theta_b/2)}{R_a \cos^2(\theta_a/2)} \right]$$

where R_a and R_b are the ranges from the central body to stations a and b , and θ_a and θ_b are the body centered angles between the stations and the source direction; e.g., $\cos \theta_a = \bar{r}_a \cdot \bar{s}/R_a$ where $\bar{s}$ is the unit vector in the direction of the source. In the case of VLBI it is advisable to include the space-time curvature effects due to the sun and the earth, and the other planets for sources with close angular positions.

Epoch and Time Intervals

The transformation from Solar System barycentric coordinate time t to proper time, $\tau = \text{TAI} + 32.184$ s. involves an annual and diurnal term and other small terms. This transformation has usually been given in the past in terms of the earth's orbital elements, terrestrial coordinates and UT. With the near universal availability of ephemeris tapes, a more convenient expression is given with sufficient accuracy (Moyer, 1981) by

$$t - \tau = \Delta T_A + \frac{2}{c^2} (\dot{\bar{r}}_B^S \cdot \bar{r}_B^S) + \frac{1}{c^2} (\dot{\bar{r}}_B^C \cdot \bar{r}_E^B) + \frac{1}{c^2} (\dot{\bar{r}}_E^C \cdot \bar{r}_A^E) \\ + \frac{\mu_J}{c^2(\mu_S + \mu_J)} (\dot{\bar{r}}_J^S \cdot \bar{r}_J^S) + \frac{\mu_{SA}}{c^2(\mu_S + \mu_{SA})} (\dot{\bar{r}}_{SA}^S \cdot \bar{r}_{SA}^S) + \frac{1}{c^2} (\dot{\bar{r}}_S^C \cdot \bar{r}_B^S).$$

where $\Delta T_A = 32.184$ s.

The superscript on the vector defines the origin of reference frame in which the vector is calculated; the subscript defines the location or body to which the vector pertains. The superscripts and subscripts are defined as follows:

- A = location of station clock on Earth which reads International Atomic Time
- E = Earth
- B = Earth-Moon barycenter
- M = Moon
- S = Sun
- C = Solar system barycenter
- J = Jupiter
- SA = Saturn

The quantity μ_X is the gravitational coefficient of body X. Some simplifications in this expression are available without significant loss of accuracy.

Doppler Frequency Shift

The relativistic correction δN , to be added to the newtonian integrated doppler count for a down radio link from an Earth orbiting satellite is given, to a sufficient accuracy, by:

$$\delta N = -\Delta t \cdot f_S \cdot \frac{1}{c^2} \left[GE \left(\frac{1}{r_R} - \frac{1}{r_S} \right) - \frac{1}{2} (v_S^2 - v_R^2) \right]$$

where:

f_S : transmitter frequency

Δt : interval of doppler count integration

r_X : geocentric distance (X=R,S)

V_X : velocity in a geocentric nonrotating frame :

S : satellite

R : Earth receiver

c : velocity of light

Appendix 10: Constraints on C_{21} and S_{21}

For Transit satellites, this formula is accurate to $10^{-12} \cdot f_s \cdot \Delta t$ (Boucher, 1978) - Although the major part of this correction is a bias absorbed by a frequency offset, a remaining periodic effect must not be neglected (Gaposchkin, Wright, 1968). Consequently, the use of the full formula given above is recommended.

References

Boucher, C., 1978, Relativistic Correction to Satellite Doppler Observation, Proceed., Meeting IAG-SSG4.45, "The Mathematical Structure of the Gravity Field," Lagonissi, Greece

Gaposchkin, E. M., Wright, J. P., 1968, A Measurable Effect of General Relativity in Satellite Orbits, SAO Special Rep. No. 283, Cambridge, Ma

Holdridge, D. B., "An Alternate Expression for Light Time Using General Relativity," 1967, JPL Space Program Summary 37-48, III, 2-4

Moyer, T. D., 1981, Celestial Mechanics, 23, 33-56, 57-68.

$$\bar{C}_{21}(\text{BIH}) = -0.70 \times 10^{-9}$$

$$\bar{S}_{21}(\text{BIH}) = 1.02 \times 10^{-9}$$

The GEM-12 gravity field solution solved for these coefficients and obtained

$$\bar{C}_{21}(\text{GEM-12}) = -1.057 \times 10^{-9}$$

$$\bar{S}_{21}(\text{GEM-12}) = -3.068 \times 10^{-9}$$

which imply a terrestrial pole location different from $\bar{x}(\text{BIH})$ and $\bar{y}(\text{BIH})$. For consistency with the desired Terrestrial Reference Frame, the $\bar{C}_{21}(\text{BIH})$ and $\bar{S}_{21}(\text{BIH})$ are recommended for use in place of $\bar{C}_{21}(\text{GEM-12})$ and $\bar{S}_{21}(\text{GEM-12})$. Because the GEM-12 coefficients have been estimated in conjunction with other coefficients, the recommendation may result in slightly increased residuals for Lagos. These comments regarding GEM-12 are valid for FGS-1231 (Starlette) as well.

REFERENCES

Lambert, K. 1971, Bulletin Geophysique 191, 263-280.

Appendix 10: Constraints on C_{21} and S_{21}

Since the CIO as realized by the BIH published values of polar motion is not coincident with the principal axis of maximum inertia, the values of C_{21} and S_{21} are nonzero. However, these coefficients consist of a constant part and a time-varying part, where the latter part results from tidal and rotational deformation of the earth. The dominant periodic variation which is associated with tides has been addressed in the appendices on solid earth and ocean tides (A5 & A6). However, because the rotational variation is much smaller than the tidal variation, the rotational contribution has not been included in the Standards.

If the adopted pole is defined by the pole position averaged over an appropriate interval, then the constant parts of C_{21} and S_{21} are

$$C_{21} = \bar{x}^C_{20}$$

$$S_{21} = -\bar{y}^C_{20}$$

where $\bar{x}$ and $\bar{y}$ are average polar motion angles (Lambeck, 1971). Consistent with the definition of the Terrestrial Reference Frame discussed in I.c., the values of $\bar{x}$ and $\bar{y}$ computed from the BIH Circular D for 1972 to 1978 yields normalized coefficients of

$$\bar{C}_{21}(\text{BIH}) = -0.10 \times 10^{-9}$$

$$\bar{S}_{21}(\text{BIH}) = 1.02 \times 10^{-9}$$

The GEM-L2 gravity field solution solved for these coefficients and obtained

$$\bar{C}_{21}(\text{GEM-L2}) = -1.057 \times 10^{-9}$$

$$\bar{S}_{21}(\text{GEM-L2}) = -3.068 \times 10^{-9}$$

which imply a terrestrial pole location different from $\bar{x}(\text{BIH})$ and $\bar{y}(\text{BIH})$. For consistency with the desired Terrestrial Reference Frame, the $\bar{C}_{21}(\text{BIH})$ and $\bar{S}_{21}(\text{BIH})$ are recommended for use in place of $\bar{C}_{21}(\text{GEM-L2})$ and $\bar{S}_{21}(\text{GEM-L2})$. Because the GEM-L2 coefficients have been estimated in conjunction with other coefficients, the recommendation may result in slightly increased residuals for Lageos. These comments regarding GEM-L2 are valid for PGS-1331 (Starlette) as well.

REFERENCES

Lambeck, K. 1971, Bulletin Geophysique 101, 263-280.

Appendix 10: Comments on C_{21} and S_{21}

Since the CIO as realized by the IAU published values of polar motion is not coincident with the principal axis of maximum inertia, the values of C_{21} and S_{21} are non-zero. However, these coefficients consist of a constant part and a time-varying part, where the latter part results from tidal and rotational deformation of the earth. The dominant periodic variation which is associated with tides has been addressed in the appendix on solid earth and ocean tides (A5 & A6). However, because the rotational variation is much smaller than the tidal variation, the rotational contribution has not been included in the Standards.

If the adopted pole is defined by the pole position averaged over an appropriate interval, then the constant parts of C_{21} and S_{21} are

$$C_{21} = \bar{x}^2 - \bar{y}^2$$

$$S_{21} = -2\bar{x}\bar{y}$$

where $\bar{x}$ and $\bar{y}$ are average polar motion angles (Lambert, 1971). Consistent with the definition of the Terrestrial Reference Frame discussed in I.C., the values of $\bar{x}$ and $\bar{y}$ computed from the IAU Circular D for 1972 to 1978 yields normalized coefficients of

$$\bar{C}_{21}(\text{IIR}) = -0.10 \times 10^{-9}$$

$$\bar{S}_{21}(\text{IIR}) = 1.02 \times 10^{-9}$$

The GEM-L2 gravity field solution solved for these coefficients and obtained

$$\bar{C}_{21}(\text{GEM-L2}) = -1.057 \times 10^{-9}$$

$$\bar{S}_{21}(\text{GEM-L2}) = -3.068 \times 10^{-9}$$

which imply a terrestrial pole location different from $\bar{x}(\text{IIR})$ and $\bar{y}(\text{IIR})$. For consistency with the desired Terrestrial Reference Frame, the $\bar{C}_{21}(\text{IIR})$ and $\bar{S}_{21}(\text{IIR})$ are recommended for use in place of $\bar{C}_{21}(\text{GEM-L2})$ and $\bar{S}_{21}(\text{GEM-L2})$. Because the GEM-L2 coefficients have been estimated in conjunction with other coefficients, the recommendation may result in slightly increased residuals for Lagos. These comments regarding GEM-L2 are valid for PCS-1971 (Scarlett) as well.

REFERENCES

Lambert, K. 1971, *Bulletin Geophysique* 101, 263-280.

Appendix 11: Tidal Variations in UT1

To properly compare UT1 results obtained at different epochs, the high frequency tidal effects must be accounted for. Thus, a standard expression for the tidal variations in UT1 is required. The periodic variations in UT1 due to tidal deformation of the polar moment of inertia have been recently rederived (Yoder, et al, 1981) including the tidal deformation of the Earth with a decoupled core. This model leads to effective Love numbers that differ from the bulk value of 0.301 because of the oceans and the fluid core which give rise to different theoretical values of the ratio k/C for the fortnightly and monthly terms. However, Yoder et al recommend the value of 0.94 for k/C for both cases. The periodic terms in UT1 that are recommended for the MERIT campaign are given on the following page, and are discussed in BIH Notice to Users of Circular D, 4 March 1983. The table includes terms due to zonal tides, with periods up to 35 days, with $k/C = 0.94$.

UT1R, ΔR , ωR represent the regularized forms of UT1, of the duration of the day Δ , and of the angular velocity of the Earth, ω .

The units are 10^{-4} s for UT, 10^{-5} s for Δ , and 10^{-14} rad/s for ω .

Reference

Yoder, C. F., Williams, J. G., Parke, M. E., 1981, J. Geophys. Res., 86, pp 881-891

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APPENDIX 11, Table 1: Terms Due to Zonal Tides, With Periods Up to 35 Days

ARGUMENT*						PERIOD	UT1-UT1R	A-AR	$\omega-\omega R$
N	1	1'	F	D	Ω	Days	Coefficient of Sin (Argument)	Coefficient of Cos (Argument)	
1	1	0	2	2	2	5.64	-0.02	0.3	- 0.2
2	2	0	2	0	1	6.85	-0.04	0.4	- 0.3
3	2	0	2	0	2	6.86	-0.10	0.9	- 0.8
4	0	0	2	2	1	7.09	-0.05	0.4	- 0.4
5	0	0	2	2	2	7.10	-0.12	1.1	- 0.9
6	1	0	2	0	0	9.11	-0.04	0.3	- 0.2
7	1	0	2	0	1	9.12	-0.41	2.8	- 2.4
8	1	0	2	0	2	9.13	-0.99	6.8	- 5.8
9	3	0	0	0	0	9.18	-0.02	0.1	- 0.1
10	-1	0	2	2	1	9.54	-0.08	0.5	- 0.5
11	-1	0	2	2	2	9.56	-0.20	1.3	- 1.1
12	1	0	0	2	0	9.61	-0.08	0.5	- 0.4
13	2	0	2	-2	2	12.81	0.02	- 0.1	0.1
14	0	1	2	0	2	13.17	0.03	- 0.1	0.1
15	0	0	2	0	0	13.61	-0.30	1.4	- 1.2
16	0	0	2	0	1	13.63	-3.21	14.8	-12.5
17	0	0	2	0	2	13.66	-7.76	35.7	-30.1
18	2	0	0	0	-1	13.75	0.02	- 0.1	0.1
19	2	0	0	0	0	13.78	-0.34	1.5	- 1.3
20	2	0	0	0	1	13.81	0.02	- 0.1	0.1
21	0	-1	2	0	2	14.19	-0.02	0.1	- 0.1
22	0	0	0	2	-1	14.73	0.05	- 0.2	0.2
23	0	0	0	2	0	14.77	-0.73	3.1	- 2.0
24	0	0	0	2	1	14.80	-0.05	0.2	- 0.2
25	0	-1	0	2	0	15.39	-0.05	0.2	- 0.2
26	1	0	2	-2	1	23.86	0.05	- 0.1	0.1
27	1	0	2	-2	2	23.94	0.10	- 0.3	0.2
28	1	1	0	0	0	25.62	0.04	- 0.1	0.1
29	-1	0	2	0	0	26.88	0.05	- 0.1	0.1
30	-1	0	2	0	1	26.98	0.18	- 0.4	0.3
31	-1	0	2	0	2	27.09	0.44	- 1.0	0.9
32	1	0	0	0	-1	27.44	0.53	- 1.2	1.0
33	1	0	0	0	0	27.56	-8.26	18.8	-15.9
34	1	0	0	0	1	27.67	0.54	- 1.2	1.0
35	0	0	0	1	0	29.53	0.05	- 0.1	0.1
36	1	-1	0	0	0	29.80	-0.06	0.1	- 0.1
37	-1	0	0	2	-1	31.66	0.12	- 0.2	0.2
38	-1	0	0	2	0	31.81	-1.82	3.6	- 3.0
39	-1	0	0	2	1	31.96	0.13	- 0.3	0.2
40	1	0	-2	2	-1	32.61	0.02	- 0.0	0.0
41	-1	-1	0	2	0	34.85	-0.09	0.2	- 0.1

- * 1 = $134^{\circ}.96 + 13^{\circ}.064993(\text{MJD}-51544.5)$ Mean Anomaly of the Moon
 1' = $357^{\circ}.53 + 0^{\circ}.0985600(\text{MJD}-51544.5)$ Mean Anomaly of the Sun
 F = $93^{\circ}.27 + 13^{\circ}.229350(\text{MJD}-51544.5)$ L- Ω : L: Mean Longitude of the Moon
 D = $297^{\circ}.85 + 12^{\circ}.190749(\text{MJD}-515.44.5)$ Mean Elongation of the Moon from the Sun
 Ω = $135^{\circ}.04 - 0^{\circ}.052954(\text{MJD}-51544.5)$ Mean Longitude of the Ascending Node of the Moon

Appendix 12: Radio Source Positions

The extragalactic radio sources used for geodetic VLBI observations generally have finite angular size, with complex, time varying, and wavelength dependent brightness distributions. The "effective coordinates" of the sources are therefore dependent, at the milliarcsecond level, on the configuration of the VLBI observing network, the observing frequencies, the temporal distribution of the observations, and other factors. Since the comprehensive catalogues and source structure maps which would allow the effective coordinates of the sources to be computed at the precise epoch of each observation are not available, and since the observation errors are not far below the milliarcsecond level, the practice is to include the source coordinates in the parameters to be estimated in the least squares solution performed to obtain the geodetic parameters. The resulting source position catalogues are not universally applicable and therefore it would not, at the present state-of-the-art, be useful to adopt a standard VLBI source catalogue. However, researchers may find it useful (for use as a priori values and for intercomparisons) to have the current best fitting source coordinates from ongoing observing programs.

Table 1 lists source positions derived at the National Geodetic Survey from observations collected during the MERIT short campaign and under project POLARIS, from September 9, 1980, through December 21, 1982. The nominal observing wavelength was 3.8 cm, although observations were made at 13 cm for ionosphere corrections only. The reference source, 3 C 273 B, has been used to fix the zero point of the right ascension of this catalog. The adopted right ascension of 3 C 273 B is $12^{\text{h}}29^{\text{m}}6^{\text{s}}.6997$. For more detailed information, see Robertson and Carter (1982a, 1982b).

Table 2 lists the JPL 1983-2 catalog which includes 104 extragalactic radio sources and is based on a single multiparameter fit to approximately 2400 VLBI observations extending from August 1971 to February 1980. To match the definition currently used by other VLBI groups, the value $12^{\text{h}}29^{\text{m}}6^{\text{s}}.6997$ was also adopted in this work for the right ascension of the reference source, 3C 273 B. This approach is a temporary convenience until alignment with the celestial reference frame defined by the DE200/LE200 ephemeris system is completed. For alignment of the axes of the earth-fixed frame with the CIO frame, a preliminary fit minimizes, over the span of the observations, the rms deviation of interferometrically measured UT1 and polar motion from BIH published values. In subsequent fits, the UT/PM solve-for values obtained in this fit for two strong sessions (reference days: 1979/12/20-21) are assigned as exactly known quantities. With this approach, subsequent UT/PM values and the axes of the earth-fixed frame are aligned on average with the conventional definitions in the best way provided by the data in hand. To prevent a singularity in the fit, the DSS-14 station coordinates (Goldstone, California) were held fixed at the values derived from spacecraft tracking (JPL station locations set LS111A). Thirteen of the sources solved for in the multiparameter fit are not included in this short version of the JPL 1983-2 catalog, either because the measurements were made solely on short baselines, or were judged to have inadequate redundancy. For further details see TDA Progress Report 42-73, dated May 15, 1983; "Radio Interferometric Determination of Source Positions, Intercontinental Baselines, and Earth Orientation With Deep Space Network Antennas - 1971 to 1980," by J. B. Thomas, O. J. Sovers, J. L. Fanelow, E. J. Cohen, G. H. Purcell, Jr., D. H. Rogstad, L. J. Skjerve, D. J. Spitzmesser.

Appendix 12: Table 1; NGS Radio Source Catalog

Source	Rt. Asc.			(Formal) Sigma	Declination			(Formal) Sigma
	h	m	s	s	d	m	s	s
0106+013	1	8	38.7710	0.00002	1	35	0.325	0.0009
0212+735	2	17	30.8134	0.00005	73	49	32.623	0.0002
0224+671	2	28	50.0517	0.00004	67	21	3.031	0.0002
0234+285	2	37	52.4057	0.00002	28	48	8.992	0.0003
0235+164	2	38	38.9300	0.00002	16	36	59.280	0.0006
0355+508	3	59	29.7473	0.00002	50	57	50.163	0.0001
0552+398	5	55	30.8057	0.00002	39	48	49.166	0.0002
0742+103	7	45	33.0596	0.00009	10	11	12.687	0.0026
0851+202	8	54	48.8749	0.00002	20	6	30.640	0.0004
0923+392	9	27	3.0138	0.00002	39	2	20.851	0.0002
1226+023	12	29	6.6997	---	2	3	8.597	0.0009
1404+286	14	7	0.3942	0.00002	28	27	14.689	0.0003
1637+574	16	38	13.4561	0.00003	57	20	23.981	0.0002
1642+690	16	42	7.8481	0.00003	68	56	39.757	0.0002
1641+399	16	42	58.8098	0.00002	39	48	36.996	0.0002
1928+738	19	27	48.4945	0.00014	73	58	1.573	0.0009
2134+004	21	36	38.5861	0.00002	0	41	54.222	0.0010
2200+420	22	2	43.2912	0.00002	42	16	39.984	0.0002
2251+158	22	53	57.7478	0.00002	16	8	53.566	0.0005

References

Robertson, D. S. and Carter, W. E., 1982A, High Precision Earth Rotation and Earth Moon Dynamics by O. Calame, D. Reidel Co., Dordrecht, Holland, 97-122

Robertson, D. S. and Carter, W. E., 1982B, Operation of the National Geodetic Survey Polaris Network Proceedings of Symposium No. 5: Geodetic Applications of Radio Interferometry, NOAA Technical Report NOS 95 NGS 24, pp 63-70

Appendix 12; Table 2

JPL 1983-2 Radio Source Catalogue (J2000.0).

IAU name	Common name	Average obs. epoch	Right ascension			Error (σ)	Declination			Error (σ)
			h	m	s		d	m	s	
0008-264	P 0008-264	1980.05	0	11	1.24747	0.00039	-26	12	33.3891	0.0053
0104-408	P 0104-408	1979.43	1	6	45.10824	0.00023	-40	34	19.9640	0.0035
0106+013	P 0106+01	1978.39	1	8	38.77105	0.00011	1	35	0.3174	0.0026
0111+021	P 0111+021	1980.04	1	13	43.14505	0.00168	2	22	17.3155	0.0254
0113-118	P 0113-118	1978.85	1	16	12.52214	0.00067	-11	36	15.4375	0.0103
0133+476	DA 55	1979.14	1	36	58.59495	0.00018	47	51	29.1053	0.0013
0202+149	P 0202+14	1980.02	2	4	50.41405	0.00012	15	14	11.0461	0.0024
0224+671	DW 0224+67	1977.48	2	28	50.05199	0.00032	67	21	3.0339	0.0019
0234+285	CTD 20	1980.02	2	37	52.40585	0.00014	28	48	8.9942	0.0021
0235+164	GC 0235+16	1980.04	2	38	38.93026	0.00012	16	36	59.2767	0.0023
0300+470	DE 400	1978.39	3	3	35.24246	0.00024	47	16	16.2831	0.0019
0316+413	3C 84	1978.72	3	19	48.16043	0.00019	41	30	42.1074	0.0019
0332-403	P 0332-403	1977.84	3	34	13.65384	0.00037	-40	8	25.3969	0.0044
0333+321	NRAO 140	1977.61	3	36	30.10794	0.00016	32	18	29.3448	0.0017
0336-019	CTA 26	1979.52	3	39	30.93773	0.00013	-1	46	35.8004	0.0029
0355+508	NRAO 150	1978.60	3	59	29.74801	0.00026	50	57	50.1688	0.0022
0402-362	P 0402-362	1978.07	4	3	53.74941	0.00044	-36	5	1.9132	0.0054
0406+121	GC 0406+12	1980.03	4	9	22.00860	0.00014	12	17	39.8426	0.0055
0420-014	P 0420-01	1977.97	4	23	15.80052	0.00020	-1	20	33.0642	0.0037
0420+417	VRO 41.04.01	1979.72	4	23	56.01004	0.00026	41	50	2.7185	0.0033
0430+052	3C 120	1977.28	4	33	11.09592	0.00025	5	21	15.6142	0.0040
0434-188	P 0434-188	1980.02	4	37	1.48289	0.00057	-18	44	48.6198	0.0086
0438-436	P 0438-43	1977.87	4	40	17.17941	0.00033	-43	33	8.6054	0.0040
0440-003	NRAO 190	1976.36	4	42	38.66089	0.00051	-0	17	43.4243	0.0080
0451-282	P 0451-28	1980.02	4	53	14.64585	0.00048	-28	7	37.3195	0.0062
0528+134	P 0528+134	1980.03	5	30	56.41692	0.00012	13	31	55.1501	0.0022
0537-441	P 0537-441	1978.46	5	38	50.36073	0.00028	-44	5	8.9386	0.0037
0552+398	DA 193	1977.55	5	55	30.80616	0.00022	39	48	49.1667	0.0019
0605-085	P 0605-08	1978.96	6	7	59.69940	0.00070	-8	34	49.9881	0.0100
0607-157	P 0607-15	1978.52	6	9	40.94952	0.00025	-15	42	40.6778	0.0044
0723-008	DW 0723-00	1979.99	7	25	50.63977	0.00020	-0	54	56.5434	0.0038
0727-115	P 0727-11	1977.93	7	30	19.11287	0.00024	-11	41	12.6140	0.0043
0735+178	P 0735+17	1977.85	7	38	7.39401	0.00022	17	42	18.9934	0.0036
0738+313	DI 363	1977.01	7	41	10.70377	0.00043	31	12	0.2264	0.0054
0742+103	DW 0742+10	1978.21	7	45	33.05953	0.00013	10	11	12.6897	0.0023
0748+126	P 0748+126	1980.00	7	50	52.04562	0.00017	12	31	4.8263	0.0031
0814+425	DJ 425	1977.83	8	18	16.00000	0.00023	42	22	45.4144	0.0018
0823+033	P 0823+033	1980.01	8	25	50.33852	0.00018	3	9	24.5130	0.0033
0827+243	B2 0827+24	1979.76	8	30	52.08663	0.00034	24	10	59.8105	0.0044
0836+710	4C 71.07	1979.64	8	41	24.36807	0.00043	70	53	42.1772	0.0020
0851+202	DJ 287	1978.04	8	54	48.87506	0.00013	20	6	30.6363	0.0018
0859-140	P 0859-14	1977.80	9	2	16.83076	0.00081	-14	15	30.8847	0.0123
0859+470	DJ 499	1977.92	9	3	3.99136	0.00076	46	51	4.1266	0.0051
0923+392	4C 39.25	1978.52	9	27	3.01394	0.00013	39	2	20.8497	0.0012
0952+179	AD 0952+17	1979.98	9	54	56.82357	0.00078	17	43	31.2228	0.0126
1004+141	GC 1004+14	1980.01	10	7	41.49848	0.00047	13	56	29.5911	0.0063
1034-293	P 1034-293	1980.00	10	37	16.07921	0.00030	-29	34	2.8183	0.0042
1038+064	OL 064.5	1980.01	10	41	17.16237	0.00020	6	10	16.9218	0.0382
1040+123	3C 245	1980.03	10	42	44.60596	0.00036	12	3	31.2536	0.0049
1055+018	P 1055+01	1979.73	10	58	29.60516	0.00011	1	33	58.8174	0.0025
1104-445	P 1104-445	1977.74	11	7	8.69332	0.00047	-44	49	7.6227	0.0047
1111+149	GC 1111+14	1980.03	11	13	58.69532	0.00048	14	42	26.9449	0.0061

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Appendix 12; Table 2 (continued)

IAU name	Common name	Average obs. epoch	Right ascension			Error (σ)	Declination			Error (σ)
			h	m	s		d	m	s	
1123+264	P 1123+26	1980.02	11	25	53.71196	0.00019	26	10	19.9738	0.0023
1127-145	P 1127-14	1978.70	11	30	7.05233	0.00016	-14	49	27.3941	0.0033
1144-379	P 1144-379	1978.73	11	47	1.37021	0.00022	-38	12	11.0305	0.0034
1148-001	P 1148-00	1978.09	11	50	43.87056	0.00040	-0	23	54.2102	0.0064
1222+037	P 1222+037	1980.03	12	24	52.42221	0.00021	3	30	50.2808	0.0038
1226+023	3C 273	1978.62	12	29	6.69970	...	2	3	8.5914	0.0025
1228+126	3C 274	1980.04	12	30	49.42342	0.00031	12	23	28.0376	0.0043
1244-255	P 1244-255	1980.02	12	46	46.80184	0.00025	-25	47	49.2957	0.0037
1253-055	3C 279	1978.24	12	56	11.16647	0.00038	-5	47	21.5321	0.0063
1308+326	B2 1308+32	1980.02	13	10	28.66381	0.00013	32	20	43.7788	0.0015
1313-333	OP-322	1978.15	13	16	7.98528	0.00031	-33	38	59.1782	0.0041
1334-127	DW 1335-12	1977.96	13	37	39.78288	0.00028	-12	57	24.7031	0.0043
1342+663	GC 1342+663	1980.12	13	44	8.67956	0.00053	66	6	11.6365	0.0025
1354+195	P 1354+19	1980.02	13	57	4.43660	0.00017	19	19	7.3665	0.0027
1418+546	GC 1418+54	1980.13	14	19	46.59754	0.00019	54	23	14.7823	0.0015
1430-178	OQ-151	1980.05	14	32	57.68946	0.00054	-18	1	35.2438	0.0080
1502+106	OR 103	1979.35	15	4	24.97966	0.00011	10	29	39.1945	0.0023
1510-089	P 1510-08	1978.18	15	12	50.53332	0.00051	-9	5	59.8409	0.0079
1519-273	P 1519-273	1980.03	15	22	37.67552	0.00022	-27	30	10.7889	0.0035
1555+001	DW 1555+00	1976.86	15	57	51.43418	0.00033	-0	1	50.4203	0.0052
1611+343	DA 406	1977.37	16	13	41.06409	0.00025	34	12	47.9082	0.0026
1633+382	GC 1633+38	1980.04	16	35	15.49283	0.00013	38	8	4.4985	0.0013
1638+398	NRAO 512	1979.50	16	40	29.63258	0.00015	39	46	46.0278	0.0014
1641+399	3C 345	1978.28	16	42	58.80983	0.00013	39	48	36.9928	0.0012
1656+053	DW 1656+05	1978.85	16	58	33.44733	0.00061	5	15	16.4383	0.0093
1717+178	GC 1717+17	1980.07	17	19	13.04837	0.00022	17	45	6.4352	0.0037
1730-130	NRAO 530	1979.13	17	33	2.70553	0.00018	-13	4	49.5460	0.0038
1738+476	DT 465	1978.70	17	39	57.12566	0.00078	47	37	58.3768	0.0045
1741-038	P 1741-038	1977.44	17	43	58.85676	0.00027	-3	50	4.6252	0.0046
1749+701	1749+701	1979.45	17	48	32.83875	0.00060	70	5	50.7750	0.0032
1807+698	3C 371	1978.96	18	6	50.67971	0.00026	69	49	28.1088	0.0010
1821+107	P 1821+10	1980.06	18	24	2.85524	0.00013	10	44	23.7698	0.0048
1921-293	OV-236	1978.47	19	24	51.05564	0.00044	-29	14	30.1133	0.0055
1933-400	P 1933-400	1979.86	19	37	16.21675	0.00059	-39	58	1.5528	0.0061
1958-179	OV-198	1979.30	20	0	57.09073	0.00037	-17	48	57.6761	0.0055
2021+614	DW 637	1978.47	20	22	6.68158	0.00095	61	36	58.8193	0.0055
2029+547	OW 551	1980.02	20	31	47.95842	0.00040	54	55	3.1495	0.0037
2030+121	P 2029+121	1980.06	20	31	54.99410	0.00019	12	19	41.3436	0.0034
2113+293	B2 2113+29B	1979.83	21	15	29.41343	0.00015	29	33	38.3663	0.0024
2134+004	P 2134+004	1977.17	21	36	38.58616	0.00017	0	41	54.2150	0.0038
2145+067	P 2145+06	1978.52	21	48	5.45853	0.00011	6	57	38.6057	0.0023
2149+056	OX 082	1980.06	21	51	37.87530	0.00017	5	52	12.9556	0.0034
2155-152	OX-192	1978.66	21	58	6.28154	0.00072	-15	1	9.3263	0.0109
2200+420	VRD 42 22 01	1978.05	22	2	43.29125	0.00016	42	16	39.9839	0.0014
2230+114	CTA 102	1978.45	22	32	36.40897	0.00050	11	43	50.9052	0.0068
2234+282	GC 2234+28	1980.04	22	36	22.47076	0.00013	28	28	57.4168	0.0018
2243-123	OY-172.6	1979.27	22	46	18.23184	0.00014	-12	6	51.2764	0.0033
2245-328	P 2245-328	1979.55	22	48	38.68551	0.00024	-32	35	52.1861	0.0036
2251+158	GC 454.3	1977.56	22	53	57.74779	0.00015	16	8	53.5658	0.0027
2253+417	3C 2253+41	1980.11	22	55	36.70799	0.00019	42	2	52.5370	0.0030
2320-035	P 2320-035	1980.00	23	23	31.95363	0.00021	-3	17	5.0216	0.0044
2345-167	P 2345-16	1977.98	23	48	2.60846	0.00035	-16	31	12.0233	0.0052

Appendix 13: Lunar and Planetary Ephemerides

The lunar and planetary ephemeris recommended for the MERIT campaign is Development Ephemeris Number (DE200/LE200). The U. S. Naval Observatory has adopted these ephemerides to form the basis for the Astronomical Almanac starting in 1984.

The ephemerides provide, by themselves, a dynamically consistent system in a reference frame that has been accurately adjusted to the dynamical equinox of J2000.0. Furthermore, the relative positions and velocities of the four inner planets and moon are well-determined and their mean motions are accurately represented with respect to inertial space. These statements are now discussed.

The ephemerides represent the results of numerical integrations of the equations of motion governing the motions of the major bodies in the solar system. Two assumptions are made: 1) the equations of motion accurately represent our understanding of the physical laws of nature, at least to the presently observable accuracy, and 2) the numerical integration program is sufficiently accurate. These two assumptions alone provide a dynamically consistent system - one which is actually physically possible in inertial space. Of course, it may not be an accurate representation of our own solar system. This depends only on the choice of initial conditions and the accuracy of other relevant parameters which enter into the equations of motion (e.g., the planetary masses). The accuracy of the initial conditions and parameters, in turn, are a direct function of the fit to the observational data.

Very accurate mass values for the planets now exist out through Saturn. Also, accurate range measurements between the Earth and another planet determine the shapes and relative orientations of the two orbits in question. Furthermore, it may be shown that range measurements are sufficient by themselves to determine the mean motions of the Earth and the planet with respect to inertial space. Earth-Mars spacecraft ranging from Mariner 9 and the Viking Landers yield inertial mean motions to an accuracy of $\pm 0''.02/\text{century}$.

Lunar laser ranging data determine the orbit of the moon. Furthermore, since these data are sensitive to both the Earth's of-date true equator and to the orbital plane of the Earth about the Sun (instantaneous ecliptic), the obliquity of the ecliptic is well-determined over the time span of this data (mean epoch of 1975). The accuracy here is $\sigma_e(1975) \leq 0''.01$.

With such an accurately determined system (relative positions and velocities, inertial mean motions, true obliquity), one may locate the dynamical equinox at J2000.0 to a high degree of precision. One starts by precessing the Earth's equator to J2000.0 using the 1976 IAU value of precession. Then, at a number of selected points (over a time span of 1470 years in the case of DE200), one computes the right ascension of the ascending node of the plane normal to the angular momentum vector of the Earth-Moon barycenter about the Sun. Using a spectral analysis, one next identifies the relevant contributing periodic terms from the planetary perturbations. Finally, one fits the points using a time-polynomial along with the periodic terms. The constant term of the time

polynomial represents the location of the dynamical equinox. A simple rotation of the ephemeris frame puts the ephemeris onto the dynamical equinox.

It should be noted that there are two different definitions of the dynamical equinox: 1) "the time-average of the right ascension of the ascending node of the plane which is normal to the instantaneous angular momentum vector of the Earth-Moon barycenter about the Sun," and 2) "the right ascension of the ascending node of the rotating plane which always contains the mean Earth-Moon barycenter." It may be shown that $\alpha\varphi(2) - \alpha\varphi(1) = 0''.09366$ for J2000.0. In that the second definition has been used classically and is the one assumed by Fricke in determining the equinox of the FK4, it will be adopted here. As such, the final rotation of the ephemeris, mentioned above, will have been corrected for this difference. A similar situation exists with the definition of the mean obliquity, where $\bar{e}(2) - \bar{e}(1) = 0''.00334$. Here, also, the second definition (obliquity of the rotating plane) has been quoted for the mean obliquity of DE200. These definitions have been discussed by Standish (1981).

One may note that the reference frame of the ephemerides will not strictly coincide with the origin of the FK5 catalog system. The difference will be the amount by which the origin of the FK5 itself fails to coincide with the dynamical equinox of J2000.0. However, the ephemeris-FK5 difference should actually be much smaller than it would be if an attempt were made to align the ephemeris system directly to the FK5 through the use of optical planetary observations. As such, the above procedure for orienting the planetary ephemeris to the dynamical equinox of J2000.0 is strongly justified.

Associated with the ephemerides is the set of astronomical constants used in the creation of the ephemerides. Many of these values do not agree exactly with those of the IAU 1976. The difference has been necessary in order to provide a "best fit" in the least squares sense to the observational data. These constants are provided with the ephemerides, physically on the magnetic tape. For a reduction of data with respect to the ephemerides, one should use this set of constants. Such a procedure is valid and justified since the set of constants is well-defined and is readily available with the ephemerides themselves.

References

Standish, E. M., 1981, *Astron. Astrophys.*, 101, L17

- Merit Standards -

APPENDIX 14
GEM-L2 NORMALIZED COEFFICIENTS
($\times 10^6$)

ZONALS

INDEX		VALUE	INDEX		VALUE	INDEX		VALUE	INDEX		VALUE
N	M		N	M		N	M		N	M	
* 2	0	-484.16499	3	0	0.95772	4	0	0.54127	5	0	0.06924
7	0	0.09237	8	0	0.05088	9	0	0.02769	10	0	0.05334
12	0	0.03852	13	0	0.04288	14	0	-0.02045	15	0	0.00286
17	0	0.01486	18	0	0.01162	19	0	0.00073	20	0	0.02689
22	0	-0.00239	23	0	-0.02047	24	0	-0.00282	25	0	0.00151
27	0	0.01097	28	0	-0.02263	29	0	-0.01127			

SECTORIALS AND TESSERALS

INDEX		VALUE		INDEX		VALUE		INDEX		VALUE	
N	M	C	S	N	M	C	S	N	M	C	S
** 2	1	-0.00106	-0.00307	3	1	2.02882	0.24969	4	1	-0.53520	-0.46629
5	1	-0.05400	-0.09510	6	1	-0.07489	0.01773	7	1	0.26915	0.09374
8	1	0.02321	0.06138	9	1	0.15543	0.01703	10	1	0.08261	-0.13442
11	1	0.00068	-0.01344	12	1	-0.06461	-0.05435	13	1	-0.03591	0.03623
14	1	-0.01763	0.05171	15	1	-0.01791	0.00030	16	1	0.02899	-0.00991
17	1	-0.00871	-0.02421	18	1	0.00265	-0.00214	19	1	-0.03652	-0.00351
20	1	0.00570	-0.02189	21	1	-0.01301	0.00741	22	1	0.00281	0.00524
23	1	0.00285	0.00927	24	1	-0.00684	-0.00285	25	1	0.01246	-0.00529
2	2	2.43791	-1.39918	3	2	0.90403	-0.61594	4	2	0.35465	0.66083
5	2	0.65096	-0.33063	6	2	0.05028	-0.35499	7	2	0.33473	0.10701
8	2	0.07422	0.04809	9	2	0.02584	-0.03132	10	2	-0.08041	-0.01170
11	2	0.04616	-0.09373	12	2	0.00715	-0.01034	13	2	0.02318	-0.03862
14	2	-0.03199	0.04065	15	2	0.01423	-0.02580	16	2	-0.00275	0.00841
17	2	-0.00775	0.01031	18	2	0.00749	0.02250	19	2	0.01145	-0.00576
20	2	-0.00090	0.00143	21	2	0.01694	0.00744	22	2	-0.00077	-0.01265
3	3	0.72315	1.41520	4	3	0.99325	-0.20270	5	3	-0.45002	-0.21279
6	3	0.06030	0.00178	7	3	0.24609	-0.21509	8	3	-0.00560	-0.08863
9	3	-0.15615	-0.09936	10	3	-0.01610	-0.16891	11	3	-0.02191	-0.13229
12	3	0.06697	0.03004	13	3	-0.02825	0.07916	14	3	0.01665	-0.01102
15	3	0.02950	0.01047	16	3	-0.00701	-0.02406	17	3	-0.01148	0.00962
18	3	-0.00422	-0.00173	19	3	0.00045	0.00023	20	3	-0.01551	0.00928
21	3	0.00460	0.00318	22	3	0.00058	0.01083	4	4	-0.19210	0.30701
5	4	-0.29163	0.04959	6	4	-0.10190	-0.46823	7	4	-0.28677	-0.12730
8	4	-0.24414	0.07443	9	4	-0.00997	0.00946	10	4	-0.09734	-0.06744
11	4	-0.04491	-0.05961	12	4	-0.07182	-0.00841	13	4	-0.02524	0.00968

* C_{20} does not include the zero frequency term; see Appendix 5 (Eq. 5) for adjusted value.

** C_{21} and S_{21} are GEM-L2 values; see Appendix 10 for recommended values.

- Merit Standards -

GEM - L2 Normalized Coefficients

($\times 10^6$)

APPENDIX 14 (CONTINUED)

SECTORIALS AND TESSERALS (CONTINUED)

INDEX N M	VALUE	
	C	S
14 4	-0.01379	0.00930
17 4	0.00450	-0.00448
20 4	-0.00166	-0.00468
5 5	0.17799	-0.66068
8 5	-0.01470	0.08008
11 5	0.04797	0.08457
14 5	0.01761	-0.01990
17 5	-0.02360	0.00927
20 5	-0.00230	0.00689
8 6	-0.06813	0.31230
11 6	0.00435	0.04243
14 6	-0.00211	-0.00766
17 6	0.00003	-0.00976
20 6	-0.00563	0.00187
9 7	-0.10256	-0.08868
12 7	-0.00999	0.04509
15 7	0.06865	0.01295
18 7	-0.00384	-0.00028
8 8	-0.12224	0.12976
11 8	0.00269	0.02225
14 8	-0.04494	0.00494
17 8	0.01423	-0.00082
20 8	-0.00214	-0.00324
11 9	-0.03015	0.03431
14 9	0.04251	0.01453
17 9	-0.00876	-0.01985
20 9	0.00551	0.02069
10 10	0.10891	-0.02522
13 10	0.03117	-0.03419
16 10	0.01674	0.00776
19 10	-0.01406	-0.00843
22 10	0.00141	-0.00021
13 11	-0.04370	-0.01857
16 11	0.02037	0.01117
19 11	-0.00188	0.02721
22 11	-0.00574	-0.02402
14 12	0.00815	-0.03131
17 12	0.03141	0.02155
20 12	-0.01117	0.02646
23 12	0.01738	0.01004

INDEX N M	VALUE	
	C	S
15 4	-0.04430	-0.00687
18 4	0.02833	0.01689
21 4	0.00256	-0.00296
6 5	-0.26580	-0.53659
9 5	0.00314	-0.06886
12 5	0.04567	0.01427
15 5	-0.01052	-0.00684
18 5	0.01235	0.01468
6 6	0.00870	-0.23801
9 6	0.04725	0.22226
12 6	0.00735	0.03337
15 6	0.02715	-0.03243
18 6	0.01601	-0.01367
7 7	0.00919	0.02799
10 7	0.00508	0.00393
13 7	-0.00202	0.00021
16 7	0.00778	-0.00257
19 7	-0.00622	0.00776
9 8	0.18658	-0.01314
12 8	-0.02500	0.02469
15 8	-0.01833	0.02496
18 8	0.00993	-0.01356
9 9	-0.05569	0.09397
12 9	0.04378	0.01404
15 9	0.01402	0.04282
18 9	-0.02329	0.02532
21 9	0.00304	-0.00339
11 10	-0.06075	-0.00632
14 10	0.05922	0.01020
17 10	0.01204	0.00997
20 10	-0.01468	-0.00957
11 11	0.04004	-0.08095
14 11	0.01777	-0.03419
17 11	-0.03894	-0.00199
20 11	0.01092	-0.01022
12 12	-0.00776	-0.01244
15 12	-0.03325	0.01656
18 12	-0.04014	-0.02431
21 12	0.00153	0.02238
24 12	-0.00853	-0.01525

INDEX N M	VALUE	
	C	S
16 4	0.04104	0.01358
19 4	-0.00323	-0.00987
22 4	-0.00780	0.00739
7 5	0.01208	0.04169
10 5	-0.06239	-0.03986
13 5	0.07560	0.04919
16 5	-0.01438	0.00103
19 5	-0.00090	-0.00176
7 6	-0.36046	0.15172
10 6	-0.03388	-0.08941
13 6	-0.03617	0.00706
16 6	0.00311	-0.03344
19 6	0.00043	-0.00079
8 7	0.06709	0.07413
11 7	0.01439	-0.08383
14 7	0.01813	-0.03150
17 7	0.01837	0.01082
20 7	-0.00978	-0.00322
10 8	0.04009	-0.08124
13 8	-0.02569	-0.00398
16 8	-0.00746	0.00811
19 8	0.00686	-0.01824
10 9	0.12351	-0.04977
13 9	0.02602	0.04295
16 9	-0.01646	-0.03521
19 9	0.00259	0.01826
22 9	0.00422	-0.00307
12 10	0.00693	0.04739
15 10	0.02971	0.00611
18 10	-0.00314	-0.00890
21 10	-0.00039	0.00208
12 11	0.01593	-0.00680
15 11	-0.00104	-0.00418
18 11	-0.00288	0.01764
21 11	-0.00568	-0.00994
13 12	-0.03219	0.09036
16 12	0.01743	0.00944
19 12	-0.01021	0.00576
22 12	-0.01614	-0.01805
25 12	-0.01241	0.00101

- Merit Standards -

GEM - L2 Normalized Coefficients

(x 10⁶)

APPENDIX 14 (CONTINUED)

SECTORIALS AND TESSERALS (CONTINUED)

INDEX N M	VALUE C S	
13 13	-0.06036	0.07051
16 13	0.01243	-0.00720
19 13	-0.01285	-0.02993
22 13	-0.02936	0.00848
25 13	0.01509	-0.00833
28 13	0.02059	0.00836
15 14	0.00400	-0.02458
18 14	-0.00866	-0.00921
21 14	0.01937	0.01022
24 14	-0.01684	0.00360
27 14	0.02345	0.00589
15 15	-0.02184	-0.00570
18 15	-0.05446	-0.01612
21 15	0.01043	0.01149
24 15	0.00586	-0.00217
17 16	-0.02391	0.01326
20 16	-0.01393	0.00097
17 17	-0.01190	-0.00003
20 17	-0.01306	-0.00728
18 18	0.00199	-0.01274
21 18	0.01250	-0.01386
20 19	0.01721	0.00871
20 20	-0.00618	-0.00553
29 26	-0.01032	-0.01690
28 28	0.00425	0.00586

INDEX N M	VALUE C S	
14 13	0.02851	0.04251
17 13	0.01436	0.01985
20 13	0.02423	0.00444
23 13	-0.00229	-0.00146
26 13	-0.00332	-0.00814
29 13	-0.01111	-0.00871
16 14	-0.01947	-0.03788
19 14	0.00559	-0.01259
22 14	0.00958	0.00652
25 14	-0.02421	0.01692
28 14	-0.00535	-0.01057
16 15	-0.01312	-0.02596
19 15	-0.02227	-0.01532
22 15	0.02408	0.00008
25 15	-0.00247	-0.00172
18 16	0.01111	0.01945
21 16	-0.00008	-0.00598
18 17	0.02115	0.01066
21 17	-0.00267	-0.00293
19 18	0.03385	-0.02103
22 18	0.00909	-0.00950
21 19	0.01192	-0.00890
27 26	-0.01117	-0.00610
27 27	0.00010	-0.00300
30 28	-0.01835	-0.03486

INDEX N M	VALUE C S	
15 13	-0.02297	-0.00174
18 13	-0.01142	-0.03714
21 13	-0.01666	0.01429
24 13	0.00616	-0.00686
27 13	-0.00823	-0.01032
14 14	-0.05101	-0.00578
17 14	-0.01584	0.01085
20 14	0.01228	-0.01004
23 14	0.00863	-0.00534
26 14	0.00745	0.00118
29 14	-0.01098	0.00998
17 15	0.00097	0.00481
20 15	-0.02379	0.00874
23 15	0.01346	0.00344
16 16	-0.02921	0.01225
19 16	-0.03540	-0.01307
22 16	-0.00408	-0.00471
19 17	0.03042	-0.00578
22 17	-0.00531	-0.00377
20 18	-0.00318	0.02954
19 19	0.00971	-0.00210
22 19	-0.01801	-0.02282
28 26	0.00742	-0.00231
28 27	-0.00831	0.00257

Appendix 14: GEM-L2 Normalized Coefficients ($\times 10^6$)

References

Lerch, F. J., Klosko, S. M., and Patel, G. B., 1983, "A Refined Gravity Model From Lageos (GEM-L2)," NASA Technical Memorandum 84986

- Merit Standards -
APPENDIX 15
PGS 1331 NORMALIZED COEFFICIENTS
($\times 10^6$)

ZONALS

INDEX N M	VALUE	INDEX N M	VALUE	INDEX N M	VALUE	INDEX N M	VALUE	INDEX N M	VALUE
* 2 0	-484.16602	3 0	0.96001	4 0	0.54063	5 0	0.06748	6 0	-0.14885
7 0	0.09407	8 0	0.05015	9 0	0.02711	10 0	0.05330	11 0	-0.04816
12 0	0.04028	13 0	0.04383	14 0	-0.02461	15 0	0.00324	16 0	-0.00074
17 0	0.01829	18 0	0.01284	19 0	0.00144	20 0	0.02361	21 0	0.00026
22 0	-0.00159	23 0	-0.01625	24 0	0.00226	25 0	-0.00090	26 0	0.00430
27 0	0.00345	28 0	-0.00393	29 0	-0.00631	30 0	0.00329	31 0	-0.00619
32 0	-0.00158	33 0	-0.00110	34 0	-0.00109	35 0	0.00511	36 0	-0.00229
37 0	-0.00211	38 0	-0.00597	39 0	0.00022	40 0	-0.00163	41 0	0.00099
42 0	0.00212								

SECTORIALS AND TESSERALS

INDEX N M	VALUE C S	INDEX N M	VALUE C S	INDEX N M	VALUE C S
** 2 1	0.00535 0.00258	3 1	2.03444 0.25330	4 1	-0.53956 -0.47935
5 1	-0.05430 -0.10712	6 1	-0.07699 0.03304	7 1	0.27759 0.10389
8 1	0.02676 0.05014	9 1	0.16528 0.01493	10 1	0.07667 -0.12433
11 1	0.00678 -0.02811	12 1	-0.06051 -0.04946	13 1	-0.04612 0.03679
14 1	-0.02566 0.04018	15 1	0.01381 0.01309	16 1	0.02247 0.02443
17 1	-0.02566 -0.02926	18 1	-0.01287 -0.02221	19 1	-0.01869 0.01499
20 1	0.00712 -0.00269	21 1	-0.01375 0.03107	22 1	0.01248 0.00375
23 1	0.00164 0.02461	24 1	-0.00649 -0.00316	25 1	-0.00476 0.00426
26 1	-0.00315 -0.01084	27 1	-0.00579 -0.00614	28 1	0.00028 0.00401
29 1	0.00677 0.00296	30 1	0.00171 0.00295	31 1	0.00186 -0.00732
32 1	-0.00449 0.00479	33 1	-0.00365 -0.00506	34 1	-0.00026 0.00212
35 1	0.00225 -0.00887	36 1	0.00631 0.00588	2 2	2.42841 -1.40880
3 2	0.90260 -0.62263	4 2	0.34566 0.66042	5 2	0.64571 -0.32553
6 2	0.03887 -0.37415	7 2	0.33563 0.09329	8 2	0.07495 0.05640
9 2	0.01614 -0.02690	10 2	-0.10081 -0.04114	11 2	0.02534 -0.08871
12 2	-0.00230 0.01604	13 2	0.04855 -0.06433	14 2	-0.04443 -0.00860
15 2	-0.00879 -0.02250	16 2	-0.02961 0.02440	17 2	-0.01975 0.02016
18 2	0.00305 0.01176	19 2	0.03223 0.00159	20 2	-0.00654 0.00122
21 2	-0.00254 0.00653	22 2	-0.01899 0.00150	23 2	-0.00083 0.00901
24 2	-0.00914 0.01609	25 2	0.01014 0.00397	26 2	-0.01263 0.00458
27 2	0.00330 -0.00896	28 2	-0.01825 -0.01805	29 2	0.00237 -0.00656
30 2	-0.01492 0.00171	31 2	0.00565 0.00189	32 2	0.00027 -0.00443
33 2	-0.00260 0.00055	34 2	0.00036 0.00155	35 2	-0.00540 0.00090
36 2	-0.00109 0.00308	3 3	0.71567 1.41438	4 3	0.99620 -0.20361
5 3	-0.45214 -0.21512	6 3	0.05568 0.00215	7 3	0.24770 -0.21867

* C_{20} does not include the zero frequency term; see Appendix 5 (Eq. 5) for adjusted value.

** C_{21} and S_{21} are PGS 1331 values; see Appendix 10 for recommended values.

- Merit Standards -

APPENDIX 15 (CONTINUED)

PGS 1331 NORMALIZED COEFFICIENTS

SECTORIALS AND TESSERALS (CONTINUED)

$(\times 10^6)$

INDEX N M	VALUE C S
8 3	-0.01483 -0.08456
11 3	-0.03990 -0.14650
14 3	0.02754 0.01179
17 3	0.01481 0.00482
20 3	0.00174 0.02331
23 3	-0.01299 -0.00773
26 3	0.00187 0.00285
29 3	0.00232 -0.00688
32 3	-0.00559 0.00271
35 3	0.00259 -0.00044
5 4	-0.29801 0.04576
8 4	-0.24338 0.07404
11 4	-0.03714 -0.05794
14 4	0.00073 -0.02591
17 4	0.00791 0.02319
20 4	0.00259 -0.02718
23 4	-0.01175 0.01127
26 4	0.00623 -0.01003
29 4	-0.01539 -0.00984
32 4	0.00015 -0.00024
35 4	-0.00113 0.00168
6 5	-0.26419 -0.53762
9 5	-0.02136 -0.04432
12 5	0.03312 0.01500
15 5	0.01683 -0.00175
18 5	0.00175 0.03635
21 5	0.00283 -0.00593
24 5	0.00412 0.00385
27 5	0.01899 -0.00406
30 5	0.00851 -0.01264
33 5	-0.00039 0.00567
36 5	-0.00330 0.00026
8 6	-0.06299 0.30967
11 6	-0.00759 0.03653
14 6	-0.02496 -0.00233
17 6	0.00164 -0.04408
20 6	0.01258 -0.00400
23 6	-0.01111 0.01390
26 6	0.01032 -0.00228
29 6	0.00884 0.00348

INDEX N M	VALUE C S
9 3	-0.15173 -0.07662
12 3	0.04183 0.02251
15 3	0.05238 0.01654
18 3	-0.02004 -0.00404
21 3	0.02600 0.01454
24 3	-0.00688 0.00594
27 3	0.01282 0.00018
30 3	-0.00195 -0.00014
33 3	-0.00264 -0.00080
36 3	0.00125 -0.00314
6 4	-0.08850 -0.47211
9 4	-0.01271 0.01551
12 4	-0.06076 0.00397
15 4	-0.03899 -0.00029
18 4	0.06166 0.00755
21 4	-0.01030 0.00437
24 4	0.01062 0.00990
27 4	-0.00892 0.00448
30 4	-0.00356 -0.00240
33 4	0.00138 0.00061
36 4	0.00157 -0.00097
7 5	0.00094 0.01362
10 5	-0.05494 -0.04587
13 5	0.05054 0.07285
16 5	-0.00526 -0.01602
19 5	0.01271 0.02832
22 5	-0.00084 -0.00092
25 5	0.00115 -0.00236
28 5	0.00598 -0.01367
31 5	0.00160 0.00209
34 5	-0.00221 0.00202
6 6	0.00877 -0.23917
9 6	0.06684 0.21892
12 6	0.00741 0.03747
15 6	0.03230 -0.03374
18 6	0.01447 -0.01287
21 6	-0.00973 -0.00766
24 6	0.00374 -0.00603
27 6	0.00440 0.00725
30 6	0.00750 0.00527

INDEX N M	VALUE C S
10 3	-0.01417 -0.15898
13 3	-0.02557 0.09289
16 3	-0.02228 -0.03215
19 3	-0.01775 0.00450
22 3	0.01032 0.00662
25 3	-0.01852 0.00012
28 3	0.00154 0.00772
31 3	-0.00199 -0.00381
34 3	0.00253 0.00190
4 4	-0.18816 0.30022
7 4	-0.26672 -0.12005
10 4	-0.08563 -0.08363
13 4	-0.00946 -0.01818
16 4	0.05051 0.05616
19 4	0.01556 -0.00210
22 4	0.01343 0.02908
25 4	-0.00797 -0.00474
28 4	0.01009 0.01111
31 4	0.00170 -0.00569
34 4	-0.00067 -0.00017
5 5	0.16682 -0.66614
8 5	-0.02163 0.09138
11 5	0.03684 0.04940
14 5	0.02589 -0.01259
17 5	-0.01549 0.01116
20 5	-0.00213 -0.00176
23 5	0.00254 0.00717
26 5	0.01244 -0.00246
29 5	-0.00283 0.00141
32 5	0.00269 0.00049
35 5	-0.00353 -0.00083
7 6	-0.35994 0.14723
10 6	-0.04009 -0.07900
13 6	-0.03074 -0.01867
16 6	0.02268 -0.03749
19 6	-0.01488 0.03053
22 6	0.01967 -0.00801
25 6	0.00035 0.00208
28 6	0.00798 0.00589
31 6	-0.00120 0.00229

APPENDIX 15 (CONTINUED)

SECTORIALS AND TESSERALS (CONTINUED)

INDEX N M	VALUE	
	C	S
32 6	-0.00015	-0.00407
35 6	0.00010	0.00063
8 7	0.07055	0.06790
11 7	0.00466	-0.09139
14 7	0.03449	-0.01665
17 7	0.03542	-0.00998
20 7	-0.01726	0.00513
23 7	0.00673	0.00816
26 7	-0.00428	-0.00719
29 7	-0.00432	-0.00990
32 7	-0.00375	0.00022
35 7	0.00051	0.00221
9 8	0.18969	-0.00305
12 8	-0.02696	0.02102
15 8	-0.02998	0.02573
18 8	0.04094	0.00798
21 8	-0.01540	0.00674
24 8	0.01316	-0.00105
27 8	-0.00018	-0.01284
30 8	0.00159	0.00949
33 8	0.00138	0.00186
36 8	-0.00083	-0.00043
11 9	-0.02953	0.04625
14 9	0.03356	0.02353
17 9	0.00200	-0.03099
20 9	0.02519	0.00364
23 9	-0.00113	-0.01419
26 9	-0.01261	0.00347
29 9	0.00177	0.00249
32 9	0.00148	-0.00333
35 9	-0.00048	0.00010
11 10	-0.05024	-0.01522
14 10	0.03771	-0.00071
17 10	-0.00676	0.01864
20 10	-0.03215	-0.00355
23 10	0.00230	-0.00505
26 10	-0.00289	0.00422
29 10	0.00346	0.00177
32 10	0.00111	-0.00229
35 10	-0.00167	0.00113

- Merit Standards -

PGS 1331 NORMALIZED COEFFICIENTS

(x 10⁶)

INDEX N M	VALUE	
	C	S
33 6	-0.00003	-0.00152
36 6	0.00154	-0.00010
9 7	-0.11553	-0.10423
12 7	-0.01852	0.03945
15 7	0.05385	-0.00265
18 7	0.01135	0.00556
21 7	-0.01002	0.00532
24 7	-0.00470	0.00581
27 7	-0.00951	-0.00069
30 7	-0.00490	0.00008
33 7	-0.00199	-0.00016
36 7	-0.00041	0.00208
10 8	0.04633	-0.08452
13 8	-0.01089	-0.00391
16 8	-0.02323	0.00639
19 8	0.02735	-0.00034
22 8	-0.03485	0.00260
25 8	0.00569	-0.00020
28 8	0.00270	-0.00220
31 8	0.00105	-0.00140
34 8	-0.00154	0.00219
9 9	-0.05138	0.10430
12 9	0.04449	0.02885
15 9	0.01182	0.04489
18 9	-0.02213	0.02820
21 9	0.01349	0.00140
24 9	-0.01063	-0.02522
27 9	0.00354	0.00952
30 9	-0.00609	-0.00264
33 9	-0.00167	0.00081
36 9	0.00016	0.00015
12 10	-0.00536	0.03019
15 10	0.00835	0.01298
18 10	0.00421	-0.00482
21 10	-0.00701	0.00277
24 10	0.00610	0.01769
27 10	-0.01349	0.01026
30 10	-0.00489	-0.00564
33 10	-0.00232	-0.00296
36 10	-0.00034	-0.00017
34 6	0.00401	0.00155
7 7	0.00009	0.00988
10 7	0.00860	0.00027
13 7	0.00178	-0.01716
16 7	-0.00425	-0.01741
19 7	0.00977	-0.00012
22 7	0.01578	0.00158
25 7	0.00733	-0.00596
28 7	-0.00582	0.00250
31 7	-0.00131	-0.00158
34 7	-0.00041	-0.00120
8 8	-0.11679	0.12756
11 8	-0.00278	0.03048
14 8	-0.03622	-0.01167
17 8	0.03921	-0.00258
20 8	-0.00818	0.00585
23 8	-0.00051	-0.00056
26 8	-0.00051	-0.00440
29 8	-0.00969	0.01122
32 8	0.00245	0.00148
35 8	0.00205	0.00274
10 9	0.12790	-0.03793
13 9	0.02352	0.04707
16 9	-0.01939	-0.03251
19 9	0.01058	0.01536
22 9	-0.00163	0.00426
25 9	-0.02207	0.01168
28 9	0.00339	-0.00675
31 9	-0.00034	0.00227
34 9	0.00046	0.00041
10 10	0.10144	-0.01792
13 10	0.04037	-0.03896
16 10	-0.01182	0.01594
19 10	-0.03725	-0.00810
22 10	-0.00127	0.02711
25 10	0.02127	-0.00632
28 10	-0.01431	0.01041
31 10	-0.00307	-0.00137
34 10	-0.00059	-0.00001
11 11	0.04848	-0.06116

APPENDIX 15 (CONTINUED)
 SECTORIALS AND TESSERALS (CONTINUED)

INDEX N M	VALUE C S	
12 11	0.00826	-0.00812
15 11	-0.00785	0.02261
18 11	-0.01246	-0.00125
21 11	0.01157	-0.02832
24 11	0.01097	0.01716
27 11	0.00083	0.00125
30 11	-0.00842	-0.00198
33 11	-0.00097	-0.00164
36 11	0.00056	-0.00090
14 12	0.00737	-0.02965
17 12	0.02671	0.02168
20 12	-0.00356	0.01869
23 12	0.01184	-0.01352
26 12	-0.01761	0.00101
29 12	-0.01378	-0.00064
32 12	-0.00101	0.00409
35 12	0.00144	0.00063
14 13	0.02943	0.04229
17 13	0.01502	0.01536
20 13	0.02424	0.00203
23 13	-0.00807	-0.00580
26 13	-0.00720	-0.00456
29 13	-0.00574	-0.00642
32 13	0.00075	0.00206
35 13	0.00303	0.00572
15 14	0.00416	-0.02467
18 14	-0.01035	-0.01378
21 14	0.02068	0.00804
24 14	-0.01660	0.00343
27 14	0.01110	0.00493
30 14	0.00994	0.00916
33 14	0.00093	0.00131
36 14	-0.00460	-0.00571
17 15	0.00107	0.00176
20 15	-0.02322	0.00117
23 15	0.01478	-0.00100
26 15	-0.00670	0.00261
29 15	-0.01284	-0.00846
32 15	0.00816	-0.00982
35 15	-0.01118	0.00668

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PGS 1331 NORMALIZED COEFFICIENTS

(x 10⁶)

INDEX N M	VALUE C S	
13 11	-0.04911	-0.00049
16 11	0.01942	-0.00054
19 11	0.01087	0.00838
22 11	-0.00118	-0.02032
25 11	0.01303	0.00852
28 11	-0.00124	0.00847
31 11	0.00015	0.00518
34 11	-0.00172	-0.00208
12 12	-0.00576	-0.01103
15 12	-0.03677	0.01593
18 12	-0.03403	-0.00992
21 12	0.00168	0.01349
24 12	0.01466	-0.00518
27 12	-0.00816	-0.00369
30 12	0.00656	-0.00366
33 12	-0.00107	0.00233
36 12	-0.00039	0.00015
15 13	-0.02701	-0.00626
18 13	-0.00961	-0.03819
21 13	-0.01756	0.01027
24 13	-0.00070	0.00058
27 13	-0.00947	-0.00990
30 13	0.00814	0.00055
33 13	0.01094	0.00278
36 13	-0.00368	0.00369
16 14	-0.01983	-0.03955
19 14	-0.00618	-0.01309
22 14	0.00537	0.00387
25 14	-0.01582	0.01033
28 14	-0.00714	-0.01216
31 14	-0.00266	0.00325
34 14	0.00192	0.00785
15 15	-0.02478	-0.00785
18 15	-0.03890	-0.01757
21 15	0.01591	0.01211
24 15	-0.00223	-0.01151
27 15	-0.00486	-0.00125
30 15	-0.00125	-0.00132
33 15	-0.00056	-0.00190
36 15	-0.00208	0.00146

INDEX N M	VALUE C S	
14 11	0.01400	-0.03877
17 11	-0.01644	0.01618
20 11	0.01353	-0.01340
23 11	0.00405	0.02021
26 11	0.00440	0.00262
29 11	-0.00013	0.01159
32 11	-0.00185	0.00333
35 11	-0.00055	-0.00111
13 12	-0.03511	0.09126
16 12	0.01676	0.00932
19 12	-0.01109	0.00545
22 12	-0.00093	-0.00245
25 12	-0.01126	0.01244
28 12	-0.00787	0.00224
31 12	0.00037	-0.00421
34 12	0.00326	0.00103
13 13	-0.06297	0.06533
16 13	0.01220	-0.00177
19 13	-0.01157	-0.03446
22 13	-0.02624	0.01286
25 13	0.01413	-0.01063
28 13	0.00455	0.00786
31 13	-0.00544	-0.00010
34 13	0.00222	0.00474
14 14	-0.05184	-0.00634
17 14	-0.01506	0.01143
20 14	0.01186	-0.01259
23 14	0.00420	-0.00508
26 14	0.00373	0.00138
29 14	-0.00538	-0.00025
32 14	-0.00238	-0.00137
35 14	0.00454	-0.00292
16 15	-0.00982	-0.02930
19 15	-0.02288	-0.01778
22 15	0.03293	0.00803
25 15	-0.00609	-0.00559
28 15	-0.01977	-0.00065
31 15	0.00430	-0.00309
34 15	0.00303	0.01066
16 16	-0.03120	0.00328

APPENDIX 15 (CONTINUED)

SECTORIALS AND TESSERALS (CONTINUED)

INDEX N M	C	VALUE S
17 16	-0.03020	0.00186
20 16	-0.01095	-0.00237
23 16	0.00722	0.00968
26 16	0.00499	-0.01666
29 16	0.00158	-0.01357
32 16	0.00302	-0.00302
35 16	-0.00067	-0.00273
18 17	0.00883	0.00795
21 17	-0.00180	-0.00566
24 17	-0.01481	-0.00110
27 17	0.00592	-0.00314
30 17	-0.00456	-0.00528
33 17	-0.00030	0.00659
36 17	0.00460	-0.00278
20 18	0.01256	0.00677
23 18	0.00289	-0.00424
26 18	-0.01970	0.00867
29 18	0.00399	0.00625
32 18	0.00505	0.00151
35 18	-0.00231	-0.00124
20 19	-0.00522	0.01162
23 19	-0.00735	-0.00071
26 19	-0.00486	0.00556
29 19	-0.00893	0.00774
32 19	-0.00070	0.00102
35 19	0.00107	-0.00264
21 20	-0.02529	0.01728
24 20	-0.00461	-0.00223
27 20	-0.00388	0.00153
30 20	-0.00421	0.00101
33 20	0.00019	-0.00356
36 20	-0.00089	0.00193
23 21	0.01065	0.01979
26 21	-0.00256	0.00050
29 21	-0.00839	0.00121
32 21	-0.00267	0.00796
35 21	-0.00130	-0.00001
23 22	-0.02112	0.00010
26 22	0.01557	0.01097
29 22	0.00783	0.00166

- Merit Standards -

PGS 1331 NORMALIZED COEFFICIENTS

(x 10⁶)

INDEX N M	C	VALUE S
18 16	0.01370	0.00785
21 16	0.01411	-0.01121
24 16	0.00519	0.00242
27 16	0.00379	-0.00418
30 16	-0.01129	0.00088
33 16	0.00066	0.00099
36 16	0.00066	-0.00188
19 17	0.03199	-0.01282
22 17	0.01604	-0.01518
25 17	-0.01209	0.00071
28 17	0.01895	-0.00861
31 17	-0.00415	0.00061
34 17	-0.00379	0.00068
18 18	0.00550	-0.00824
21 18	0.02145	-0.00561
24 18	-0.00187	0.00062
27 18	-0.00855	0.01041
30 18	-0.00031	-0.00660
33 18	-0.00318	-0.00497
36 18	-0.00004	0.00171
21 19	-0.02584	0.01087
24 19	-0.00973	-0.00275
27 19	-0.00466	-0.01080
30 19	-0.01092	0.00204
33 19	0.00173	-0.00194
36 19	-0.00275	-0.00101
22 20	-0.01850	0.02309
25 20	-0.01005	0.00080
28 20	-0.00823	0.00291
31 20	-0.00094	-0.00477
34 20	0.00229	-0.00068
21 21	0.00421	0.01348
24 21	0.00476	0.01277
27 21	-0.00286	-0.00189
30 21	-0.00542	-0.00428
33 21	0.00122	-0.00046
36 21	0.00111	-0.00303
24 22	0.00125	0.00230
27 22	-0.00671	-0.00404
30 22	-0.00195	0.00183
19 16	-0.02209	-0.01655
22 16	0.00427	-0.00940
25 16	-0.00281	-0.01782
28 16	-0.00558	-0.01141
31 16	-0.00221	0.00660
34 16	-0.00206	-0.00265
17 17	-0.02443	-0.02451
20 17	0.00649	-0.00890
23 17	0.00017	-0.00595
26 17	-0.01057	0.00567
29 17	0.00402	-0.00299
32 17	-0.00707	0.00482
35 17	0.00203	-0.00447
19 18	0.02816	-0.00762
22 18	0.01634	-0.00875
25 18	-0.00958	0.00163
28 18	0.00548	0.00078
31 18	0.00130	-0.00091
34 18	-0.00522	-0.00260
19 19	-0.01050	0.00384
22 19	0.00577	-0.00663
25 19	-0.00177	0.00451
28 19	-0.00341	0.01353
31 19	-0.00082	0.00432
34 19	0.00326	0.00378
20 20	0.01608	0.00051
23 20	0.00862	-0.01233
26 20	0.00897	-0.01745
29 20	-0.00673	-0.00360
32 20	0.00232	-0.00386
35 20	0.00012	0.00232
22 21	-0.02629	0.02510
25 21	0.00894	0.00538
28 21	0.00463	0.00316
31 21	0.00254	0.00223
34 21	0.00041	-0.00521
22 22	-0.00923	-0.00301
25 22	-0.00931	-0.00051
28 22	-0.00173	-0.01349
31 22	-0.00599	-0.00293

APPENDIX 15 (CONTINUED)
 SECTORIALS AND TESSERALS (CONTINUED)

- Merit Standards -
 PGS 1331 NORMALIZED COEFFICIENTS
 ($\times 10^6$)

INDEX N M	C	VALUE S
32 22	-0.00542	0.00312
35 22	0.00118	0.00050
24 23	-0.00432	-0.01092
27 23	-0.00108	-0.01104
30 23	0.00420	-0.01201
33 23	-0.00320	-0.00279
36 23	0.00042	-0.00084
26 24	0.00239	0.00903
29 24	0.00294	-0.00137
32 24	-0.00982	0.00686
35 24	0.00220	0.00014
26 25	-0.00065	0.00225
29 25	-0.00574	0.00440
32 25	-0.00654	0.00327
35 25	-0.00075	0.00293
27 26	-0.00137	-0.00150
30 26	-0.01147	0.00574
33 26	0.00427	0.00449
36 26	-0.00437	0.00182
29 27	-0.00435	-0.00248
32 27	-0.00617	-0.00805
35 27	0.00242	-0.02404
29 28	0.01155	-0.00909
32 28	0.00203	-0.00151
35 28	-0.00159	-0.01907
30 29	0.00507	0.00472
33 29	-0.01811	-0.00732
36 29	0.00982	-0.00767
32 30	-0.00112	0.00414
35 30	-0.00367	0.00873
32 31	-0.00132	0.00023
35 31	0.00106	0.00143
33 32	0.00093	-0.00317
36 32	0.00380	0.00093
35 33	0.00301	-0.00102
35 34	-0.00184	0.00184
36 35	0.00084	-0.00228
40 39	-0.00001	-0.00000
43 39	-0.00008	0.00009
41 40	-0.00000	-0.00001

INDEX N M	C	VALUE S
33 22	-0.00280	-0.00493
36 22	0.00144	-0.00288
25 23	0.00801	-0.00586
28 23	0.00657	-0.01113
31 23	0.00839	0.00369
34 23	0.00059	-0.00219
24 24	-0.00161	-0.00298
27 24	-0.00586	0.00038
30 24	0.00448	-0.00221
33 24	0.00074	0.00207
36 24	0.00139	0.00009
27 25	0.01059	0.00343
30 25	0.00341	-0.00996
33 25	0.00575	-0.00561
36 25	-0.00179	0.00567
28 26	0.00714	-0.00065
31 26	-0.00518	-0.00212
34 26	0.00482	-0.00499
27 27	0.01370	-0.00524
30 27	-0.01082	0.00756
33 27	-0.01014	-0.00443
36 27	-0.00939	0.00907
30 28	-0.00406	-0.01069
33 28	-0.00329	0.00244
36 28	0.00169	-0.00020
31 29	-0.00425	-0.01243
34 29	-0.00234	-0.00779
30 30	-0.00068	0.00543
33 30	-0.00181	-0.01999
36 30	-0.00066	0.00019
33 31	0.00269	-0.00027
36 31	-0.00007	0.00406
34 32	-0.00006	-0.00019
33 33	0.00093	0.00226
36 33	0.00218	-0.00074
36 34	-0.00185	0.00134
36 36	0.00116	-0.00074
41 39	0.00002	-0.00002
44 39	-0.00009	-0.00011
42 40	0.00001	-0.00003

INDEX N M	C	VALUE S
34 22	0.00105	0.00373
23 23	0.00504	-0.00922
26 23	0.00285	0.01285
29 23	0.00509	0.00025
32 23	0.00110	-0.00225
35 23	-0.00318	0.00119
25 24	0.00980	-0.00695
28 24	0.00887	-0.00893
31 24	-0.00066	0.00057
34 24	0.00580	-0.00132
25 25	0.00521	0.00685
28 25	-0.00117	-0.01250
31 25	-0.00554	0.00474
34 25	0.00470	-0.00152
26 26	-0.00373	0.00663
29 26	0.00544	-0.00687
32 26	-0.00115	0.00492
35 26	-0.00438	-0.00188
28 27	-0.00305	0.00728
31 27	0.00658	0.01792
34 27	0.00743	0.00068
28 28	0.00630	0.00875
31 28	0.00272	-0.00447
34 28	-0.00529	-0.01401
29 29	0.00471	-0.00600
32 29	-0.00708	0.00714
35 29	0.01147	-0.00010
31 30	-0.00163	-0.00023
34 30	-0.01272	-0.00754
31 31	-0.00364	0.00039
34 31	-0.00070	0.00127
32 32	0.00399	-0.00041
35 32	0.00018	-0.00183
34 33	0.00336	0.00238
34 34	-0.00149	-0.00035
35 35	-0.00200	-0.00178
39 39	0.00000	0.00000
42 39	0.00003	0.00003
40 40	-0.00000	0.00000
43 40	0.00001	0.00005

APPENDIX 15 (CONTINUED)
SECTORIALS AND TESSERALS (CONTINUED)

INDEX N M	VALUE	
	C	S
44 40	-0.00008	0.00013
42 41	0.00011	0.00010
45 41	0.00038	-0.00280
43 42	-0.00000	-0.00001
46 42	0.00010	-0.00002
44 43	0.00000	-0.00000
47 43	0.00000	0.00002

- Merit Standards -

PGS 1331 NORMALIZED COEFFICIENTS

INDEX N M	VALUE (x 10 ⁶)	
	C	S
45 40	-0.00003	-0.00018
43 41	-0.00007	0.00060
46 41	0.00250	0.00254
44 42	-0.00002	0.00001
47 42	-0.00010	-0.00029
45 43	-0.00000	-0.00000
48 43	0.00004	-0.00006

INDEX N M	VALUE	
	C	S
41 41	0.00000	-0.00005
44 41	-0.00073	-0.00069
42 42	0.00000	-0.00000
45 42	0.00002	0.00008
43 43	0.00000	0.00000
46 43	-0.00001	0.00002

Appendix 15: PGS 1331 Normalized Coefficients ($\times 10^6$)

References

Marsh, J. G., Lerch, F. J., and Williamson, R. G., 1983, Geodynamic and Geodetic Parameter Estimation From Starlette Laser Tracking Data," to be submitted to JGR